S-59 50-348/364-CIVP 2/18/92

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

DOCKETED

'92 MAR 13 A11:59

OFFICE OF SECRETARY
DOCKETING & SERVICE
BRANCH

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: EQUIPMENT QUALIFICATION SEMINAR
FEBRUARY 6-8, 1985
319 Pages

DOCUMENT DATE: ______

DOCUMENT RECEIVED FROM: N. MERRIWEATHER (WORK FILES)

TYPE OF DOCUMENT: ______

RESPONSIVE TO ITEM NO: 39

EXEMPTION CLAIMED: NO

YES - ______

Staff Exh. 59

NUCLEAR REGULATORY COMMISSION

Docket No. 50-348/364-CivP Official Exh. No. 59

In the matter of Alabama Power Company

Staff ✓

Applicant ______ IDENTIFIED 9:09 a.m. 2/18/92

Intervenor ______ RECEIVED 2/18/92

Cont'g Off'r ______ REJECTED ______

Contractor ______

Other ______ DATE 2/18/92

Reporter L Cat[illegible] Witness ______

39-a

EQUIPMENT QUALIFICATION SEMINAR

SPONSORED BY

U. S. NUCLEAR REGULATORY COMMISSION

OFFICE OF INSPECTION & ENFORCEMENT

PRESENTED BY

NRC OFFICE OF INSPECTION & ENFORCEMENT

AND

SANDIA NATIONAL LABORATORIES

FEBRUARY 6-8, 1985

ALBUQUERQUE, NEW MEXICO

1. INTRODUCTION

There are numerous industry and NRC documents that talk about qualification. Throughout the next two days we will be referring to many of these documents. Hence, the first thing I thought I would do in this introduction is to provide a roadmap to a few of these documents.

First, let us start with the requirements. Comission regulations in 10 CFR 50 require that structures, systems, and components important to safety in a nuclear power plant be designed to accomodate the effects of environmental conditions (i.e., remain functional under postulated accident conditions) and that design control measures such as testing be used to check the adequacy of design.

Specific requirements pertaining to qualification of electric equipment important to safety are contained in 10 CFR 50.49. These requirements include a list of acceptable methods to accomplish qualification, a requirement that certain qualification information be generated by the licensee, and implementation deadline requirements.

Regulatory Guide 1.89 (revision 1, June, 1984) describes a method acceptable to the NRC staff for complying with 10 CFR 50.49. Strictly speaking, Reg Guide 1.89 does not present qualification requirements, only qualification guidance.

Reg Guide 1.89 interpretes IEEE Std. 323-1974. This is the "motherhood" IEEE standard providing qualification guidance. Prior to the final publication of Reg Guide 1.89, The IEEE revised 323, but the NRC did not base its regulatory guide on the revised 323-1983 IEEE standard.

In addition to the IEEE "motherhood" standard, IEEE has issued numerous "daughter" standards that discuss qualification practices for specific equipment types. For example, IEEE Std. 383-1974 discusses qualification practices for electric cables. This standard has been endorsed (with some modification) by NRC Reg Guide 1.131.

Two other documents are of historical regulatory importance. One is NUREG-0588. This was first issued for public comment in December, 1979. Prior to the modification of the document in response to public comments, the NRC commision endorsed NUREG-0588 as the interim positions that should be satisifed until the 10 CFR 50.49 rulemaking was finalized. Hence rather than modify NUREG-0588 in response to public comment, the NRC issued in July, 1981 an Appendix to the report that provided NRC staff response to the public comments.

A second document of historical regulatory importance is the DOR Guidelines. This document is dated November 13, 1979 and was used to evaluate reactors which had received operating licenses as of May 23, 1980.

There are numerous industry documents that provide industry perspectives concerning qualification. For example, several of the NSSS suppliers have generated reports providing their interpretation and implementation plans for qualification efforts. Two examples are:

1. General Electric's Licensing Topical Report NEDE-24326-1-P which describes the General Electric Environmental Qualification Program.

2. Westinghouse's WCAP 8587 which describes a "Methodology for Qualifying Westinghouse WRD Supplied NSSS Safety Related Electrical Equipment".

In both cases, NRC staff have reviewed these reports and if you don't agree with a position in the report you will need to discover NRC's official position.

We will be referencing these documents throughout the course. Let us start using some of these documents by defining the term qualification. Equipment qualification is a design verification process. IEEE Std. 323-1974 defines it as

> "the generation and maintenance of evidence to assure that the equipment will operate on demand, to meet the system performance requirements".

NRC Regulatory Guide 1.89 (revision 1, June 1984) states:

> "For the purpose of this guide, "qualification" is a verification of design limited to demonstrating that the electric equipment is capable of performing its safety function under significant environmental stresses resulting from design basis accidents in order to avoid common-cause failures."

Within the framework of the above two definitions there are at least seven broad questions that can be addressed during an equipment qualification inspection. These are:

1. Were the environmental conditions appropriately enveloped during the qualification effort?

2. Were functional performance requirements adequately demonstrated during the qualification effort?

3. Were the equipment installation practices and interfaces (particularly with regard to moisture intrusion problems) properly tested?

4. Were the electrical inputs to the device appropriately enveloped?

5. Was the qualification program performed in a quality

manner?

6. Is the installed item sufficiently similar to the tested item?

7. Are the maintenance requirements assumed by the qualification effort being implemented?

In this course we will discuss several of these questions. Regulatory requirements will be summarized, technical issues will be discussed, some sample inspection questions will be provided. Overall, one purpose of this course is to acquaint you with qualification information useful during inspections. This information, when coupled with an inspection process, should produce reasonable inspection results.

A second goal of this course is to suggest a useful inspection process. Typically, we at Sandia look for technical consistency. Further examination of identified inconsistencies is a means to identify both QA and Technical problem areas. In other words we believe that consistency checks are the core of the inspection process. The course will reflect this bias.

The use of consistency analysis as an inspection process has widespread use. For example, a typical Quality Assurance Programmatic Inspection asks the following two questions:

1. Are the QA manual and QA procedures consistent with 10 CFR 50, Appendix B and 10 CFR 21 requirements?

2. Are test and documentation practices consistent with the QA manual and QA procedure requirements?

Similarly, consistency analysis is a valuable part of any technical evaluation. A Technical Inspection asks some of the following four questions:

1. Are test strategy and test practices consistent with NRC requirements and recommendations (10 CFR 50, App B; 10 CFR 50.49; Regulatory Guide 1.89; etc.)?

2. Are test strategy, practices, and results self-consistent? (Inconsistencies may reflect test problems.)

3. Are test strategy, practices, and results consistent with past qualification test experiences?

4. Are test strategy, practices, and results consistent with good engineering judgement?

For an NRC inspection the first three technical questions are more pertinant than the last technical question. "Good engineering judgement" is usually too nebulous an issue to be a viable inspection criterion. Technical questions 2 and 3 may

...o appear at first glance as providing a difficult inspection ...sis. However, if the consistency approach is used, problems ...scovered in answering technical questions 2 and 3 will usually uncover nonconformances related to QA or technical requirements.

To summarize, the two goals of this course are to provide technical and programmatic information useful during qualification inspections and to suggest that a useful inspection process involves consistency analysis. To achieve these goals our course outline is as follows:

Wednesday, February 6, 1985

1. Equipment Qualification Environments including

   a. what environments need to be enveloped
   b. reasonable testing simplifications
   c. NRC and IEEE test requirements
   d. equipment necessary to monitor test conditions
   e. examples

2. Functional Performance Requirements including

   a. acceptance criteria
   b. NRC and IEEE requirements
   c. common mode versus random failures
   d. examples

Thursday, February 7, 1985

3. Interfaces and Installation Practices

4. Seismic including

   a. general seismic background
   b. seismic qualification

5. Hydrogen Burn Issues

6. Quality Assurance and the Mechanics of Qualification including

   a. 10 CFR Appendix B, 10 CFR 21, and 10 CFR 50.49
   b. purchase orders, test plans and procedures, and documentation
   c. review process and certification
   d. examples

Friday, February 8, 1985

7. Tour of Sandia test facilities used in equipment qualification research

EQUIPMENT QUALIFICATION ENVIRONMENTS

This portion of the course has several important goals. These include:

1. To become familar with typical environmental specifications applicable to equipment qualification.

2. To discuss the concept of "margin" and to understand its impact on qualification test environments.

3. To discuss reasonable testing simplifications that allow for the accomplishment of qualification testing. Topics to be considered are:

   a. What test simplifications are reasonable for simulating aging environments? We will discuss the following topics:

      i. thermal aging techniques including a discussion of the Arrhenius methodology.

      ii. radiation dose rate considerations

      iii. synergistic and sequencing effects for radiation and thermal environments.

      iv. other environments including dust, voltage and frequency variations, vibration, and mechanical cycling.

   b. What test simplifications are reasonable for simulating accident environments? We will discuss the following topics:

      i. radiation dose rate considerations

      ii. steam ramp time considerations

      iii. chemical spray considerations

      iv. synergistic effects and the importance of oxygen.

      v. superheated versus saturated steam issues

      vi. post-accident acceleration techniques

      vii. beta-gamma equivalence

4. To become familar with NRC and IEEE requirements regarding "test simplifications". Also, to become familar with some current industry practices.

Regulatory Guide 1.89 (revision 1, June, 1984) describes a method acceptable to the NRC staff for complying with the 10 CFR 50.49 requirements. This Reg Guide provides specific recommendations for acceptable techniques to calculate temperature and pressure envelopes to which equipment should be qualified. For the purposes of this course we will not review these techniques. Rather, we assume that environmental profiles contained in a licensee's Final Safety Analysis Report have received NRC staff review. Hence, environmental conditions contained in purchase orders to test laboratories and/or manufacturers typically will be acceptable for the purposes of this inspection program.

However, frequently you may encounter qualification efforts that are not based on specific purchase orders. Many manufacturers perform generic qualification analysis or testing. Thus you may encounter situations where it is useful to understand potential qualification environmental specifications

TYPICAL AGING AND ACCIDENT ENVIRONMENTS

Now let us develop a better understanding of typical aging and accident environments for nuclear reactors.

Radiation Aging

Normal operation radiation environments are typically less than 50 Mrd. For many applications, integrated doses substantially less than 50 Mrd are predicted. For example, Table 1 summarizes the 40 year integrated radiation doses for the primary containment of Limerick's BWR/4 Mark II. (Figure 1 illustrates Limerick's containment design.) A maximum value of 37 Mrd is predicted. Table 2 summarizes radiation environemts predicted by Grand Gulf's FSAR (dated 8/78). Grand Gulf is a BWR/6 Mark III. (Figure 2 illustrates a Mark III containment design; Figure 3 provides Grand Gulf's key to the Table 2 data.) Within the drywell, the maximum gamma dose is 18 Mrd. Within the secondary containment (outsidethe drywell) at the general floor area the integrated dose is only 350 rds. The auxillary steam tunnel at Grand Gulf has a maximum gamma aging dose of 2 Mrd.

Figure 4 provides a representation for some PWR containments. Unlike for BWRs, this PWR containment is not segmented into primary and secondary zones. Westinghouse's WCAP 8587, rev 5, dated April, 1982 describes a "Methodology for Qualifying Westinghouse WRD Supplied NSSS Safety Related Electrical Equipment". Table 6.2 of WCAP 8587 (See Table 3) indicates that in the general area of the PWR reactor cooling loop the 40 year gamma dose is less than 20 Mrd. Outside the loop compartment wall, a total gamma dose less than 1 Mrd is obtained.

These references suggest a wide variation in gamma radiation aging dose within containment of nuclear reactors. Therefore, generic qualification efforts are sometimes based on a 50 Mrd aging simulation (the recommended aging dose in IEEE 383-1974 for cable qualification).

A Sandia report (NUREG/CR-3156; SAND82-2559, April, 1983) discusses gamma and neutron radiation doses based on health physics measurements in non-hot spot locations. The authors conclude that a 40 year gamma total dose of ~3E+04 rads may be reasonable for the majority of non-hot spot locations. They also suggest that a neutron fluence of 2 E+09 to 3 E+14 n/cm^2 is reasonable. These health physics derived neutron fluence values are consistent with Grand Gulf FSAR predications presented in Table 2 for drywell locations.

To summarize: There is little public data on ambient radiation measurements within containment. Most qualification efforts are based on NSSS (or FSAR) predications. These predications are generally less than 50 Mrd, though on a few inspections qualification specs sometimes have indicated higher values.

Radiation Accident Conditions

The radiation accident exposure will depend on the equipment location. Tables 1 and 4 provide accident predictions for the Limerick BWR. In these tables, shielding effects that may be very important for establishing the total beta dose have not been considered. The Grand Gulf FSAR (dated 8/78) indicates that all safety related equipment is appropriately protected so that beta radiation effects can be ignored. Table 4 (for Limerick) indicates that the primary containment (drywell) integrated gamma dose for a 180 day LOCA is 46 Mrd. The integrated beta dose is over twenty times larger, exceeding 1000 Mrd. The Grand Gulf integrated accident gamma dose (Table 2) is less than 20 Mrd. The Limerick data in Table 4 indicates that initial gamma dose rates in excess of 10 Mrd/h are possibile. Initial beta dose rates in excess of 100 Mrd/h are predicted for Limerick's primary containment.

Accident dose rates and doses (Figures 5-8) are provided by Westinghouse in their WCAP 8587 document. LOCA accident scenerios generate substantially more irradiation than do steam line break accidents. Initial dose rates of 8 Mrd/h (gamma) and 100 Mrd/h (beta) are predicted. The one year total exposure is in excess of 100 Mrd (gamma) and 1000 Mrd (beta). NRC Regulatory Guide 1.89 (revision 1, dated June 1984) presents a sample calculation for the qualification radiation dose at the midpoint of a PWR having a containment free volume of 2.5 million cubic feet and a power rating of 4100 MWt. One year after the start of a LOCA, the integrated gamma dose is 15 MR while the integrated beta dose is 220 Mrd.

To summarize, accident irradiation doses depend on equipment position. Integrated one year accident gamma doses of 20 - 100 Mrd are predicted. One year accident unshielded beta doses as high as 1000 Mrd are also predicted. Because of shielding effects, beta doses at actual equipment locations may be less.

Thermal Aging Conditions:

One typically can find normal operation estimates for aging thermal environments in FSARs or NSSS equipment qualification documents. Normal operation temperatures for Limerick's primary containment (BWR/4 Mark II) are listed in Limerick's equipment qualification report as 65 F min and 150 F max (Table 1). Grand Gulf indicates in its FSAR (dtd 8/78) that normal operating temperatures inside primary containment (i.e., inside the drywell) are 112 to 135 F (Table 5). WCAP 8587 lists normal and abnormal operating environments in its Table 6.1 (our Table 6). In-containment temperatures vary from 65 F to 135 F.

Accident Steam Conditions

10 CFR 50.49 indicates that the equipment qualification program must be based on the time-dependent temperature and pressure at the location of the electric equipment important to safety. Moreover it must be established for the most severe design basis accident during or followi hich this equipment is required to remain functional. The e several acronyms used to descrit those design basis acc t events traditionally considered most severe. Th se include:

LOCA = Loss of Coolant Accident

MSLB = Main Steam Line Break

HELP = High Energy Line Break

Until the mid 1970's, the design basis event considered during qualification testing was a LOCA. It was then discovered that MSLB type cidents could cause higher initial temperatures and therefore might be considered more severe at the start of an accident.

Figures 9 and 10 provide WCAP-8587 PWR Containment Environmental Design Conditions for LOCA and MSLB accidents, respectively. Note, that according to WCAP-8587 profiles, the MSLB accident results in initial temperatures approximately 100 F higher than does the LOCA accident. For both accident scenerios the maximum pressures are in the range of 50-60 psig..

Some Limerick BWR profiles are shown in Figures 11-16. Primary containment (i.e., inside the drywell) temperatures of 330 F are achieved. The maximum predicted pressure is 44 psig.

It is of interest to list the saturated steam temperatures associated with pressures of 45 to 60 psig. At sea level we have a saturated steam temperature of 293 F for 45 psig, 298 F for 50 psig, 302 F for 55 psig, and 307 F for 60 psig. Hence, temperature specifications above 310 F will typically correspond to superheated steam conditions.

Chemical Spray

10 CFR 50.49 states in section e.3: "The composition of chemicals used must be at least as severe as that resulting from the most limiting mode of plant operation (e.g., containment spray, emergency core cooling, or recirculation from containment sump). If the composition of the chemical spray can be effected by equipment malfunctions, the most severe chemical spray environmentthat results from a single failure in the spray system must be assumed."

WCAP-8587 indicates that in-containment PWR chemical spray specifications are 2500 ppm boron buffered with 0.88% dissolved sodium hydroxide to maintain a pH of 10.5. George Masche in Systems Summary of a Westinghouse Pressurized Water Reactpr Nuclear Power Plant indicates that the containment spray system is designed to deliver, with only one pump running, enough NaOH to the containment to form an 8.8 pH solution, when combined with the refueling water and spilled reactor coolant water after the refueling waterstorage tank has been emptied. Sprays for BWRs are typically demineralized water.

Now let use our understanding of nuclear plant accident environments to assess the generic applicability of a Rockbestos analysis.

EXAMPLE 1

The following technical report was generated by Rockbestos to demonstrate that beta radiation effects are not important for a Bechtel application at Limerick. This report was subsequently attached to a generic Rockbestos qualification test plan for their chemically cross-linked polyethylene cable products. A reasonable question is whether the Rockbestos analysis has generic applicability?

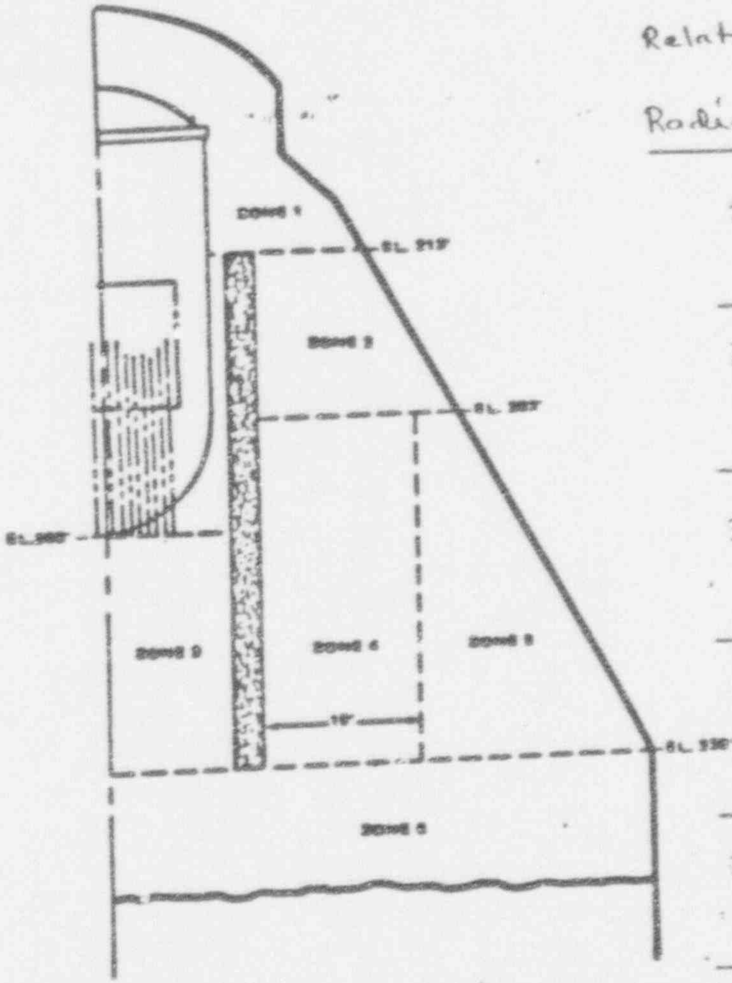
First, let us review the thrust of the Rockbestos analysis. There are two types of radiation that are postulated to occur during an accident scenerio, namely beta radiation and gamma radiation. Beta radiation typically has a very short penetration distance. Hence, Rockbestos' analysis is to demonstrate that the jacket of a multiconductor cable will stop most of the beta radiation and that the interior insulated conductors experience only a small fraction of the total beta dose. In this case Rockbestos is estimating that less than .06 Mrd total dose is received by any portion of the insulation. To perform this estimate, Rockbestos divides the beta energy spectrum into two portions: beta particles with energy less than 0.5 Mev and those with energy greater than 0.5 Mev. Their first calculation indicates that beta particles with energy less than 0.5 Mev will be stopped by a 45 mil thick jacket. Their second calculation illustrates that the beta particles with energy greater than 0.5 Mev account for only 0.06 Mrd total dose. Hence they conclude that beta radiation will not cause an electrical breakdown during the 720 hour time period after a LOCA. Their analysis is based on Bechtel supplied beta spectrum information for Limerick. Let us determine whether this analysis is applicable to other nuclear plants. By placing the analysis within a generic test plan Rockbestos is hinting that it is applicable.

To answer whether the analysis is applicable to other plants we need to refer to our understanding of typical beta accident environments for nuclear plants an_ compare our understanding with the assumptions of the Rockbestos analysis. The Rockbestos analysis is based on beta accident information supplied by Bechtel for the Limerick BWR/4 Mark II reactor. Table 1 provides Limerick estimates for accident irradiation doses. As mentioned earlier, there are large differences in both beta total dose and dose rate between the primary containment and the secondary containment. Within the primary containment initial dose rates are above 100 Mrd/h and the total beta dose for 720 hours exceeds 1000 Mrd. The initial beta dose rate in the secondary containment is orders of magnitude lower. The total beta dose for secondary containment after 720 hours is 1.0 Mrd.

We can now examine the Rockbestos analysis to determine whether the primary or secondary containment application applies. To do this we must examine the beta energy information supplied by Bechtel to Rockbestos. This analysis never indicates the total dose. However, dose rate information is supplied. At half an hour after the start of the LOCA, the dose rate is listed as 1.0E+09 Mev/cc/sec. If we convert this to Mrd/h we can compare it to Table 4 to determine whether Rockbestos' analysis is for primary or secondary containment.

1.0E+09 Mev/cc/sec = 1602 erg/cc/sec = 1.24E+06 erg/g/sec
=1.24E+04 rd/sec = 4.5E+07 rd/h

This agrees very well with the Table 1 value of 4.48E+07 rd/h. Hence Rockbestos' analysis is for a primary containment application and should be applicable in general to both BWR primary and secondary containment locations as well as to PWR locations. However, there are potential problems with the Rockbestos analysis. For example, they assume that all beta radiation with energy less than 0.5 Mev is absorbed by the jacket. However, this is a total dose of 1000 Mrd. We have to ask whether the jacket still exists. They also don't consider any shielding effects due to cable conduit or cable trays. In fact, the analysis doesn't mention installation practices. This example clearly demonstrates a recurrent fact about inspections. At the vendor and test laboratory level you will be performing inspections with an incomplete picture regarding application and installation.



LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION 8031-M-171

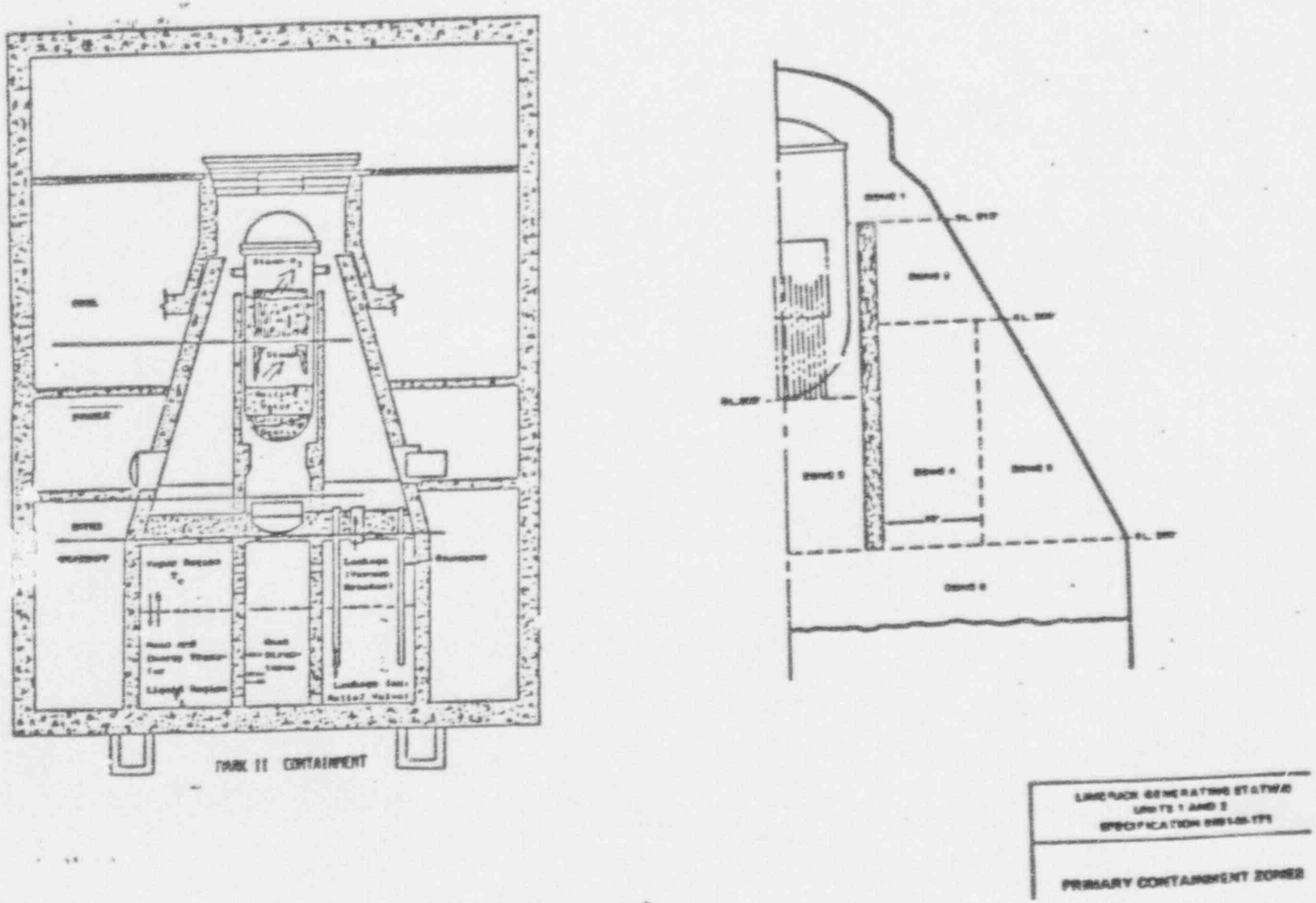
PRIMARY CONTAINMENT ZONES

Temperature: 11 zones = 65°F m / 150°F max

Relative humidity: All zones = 20% ave. / 100% max.

Radiation:	Aging Integrated DOSE (40 yrs)	LOCA DOSE (180 d.)
Zone 1	γ = 0.4 E+4 rds	γ = 4.6 E+7 rds β = 1.2 E+9 rds
Zone 2	γ = 1.0 E+7 rds	γ = 4.6 E+7 rds β = 1.2 E+9 rds
Zone 3	γ = 4.3 E+6 rds	γ = 4.6 E+7 rds β = 1.2 E+9 rds
Zone 4	γ = 1.0 E+7 rds	γ = 4.6 E+7 rds β = 1.2 E+9 rds
Zone 5	γ = ?	γ = 4.6 E+7 rds β = 1.2 E+9 rds
Zone 6	γ = 3.7 E+7 rds	γ = 4.6 E+7 rds β = 1.2 E+9 rds

Table 1 Radiation environments for Limerick primary containment. (BWR/4 Mark II)



Schematic of the Limerick Containment (Mark II)
Detailing IMCOR Analysis

Figure 1

Table 2

RADIATION ACCIDENT CONDITIONS -- GRAND GULF BWR/6 MARK III

I. Drywell

Equipment or Area	Radiation Type	Operating Dose Rate (1)	Design Basis Accident Type	Design Basis Accident Dose Rate (1)	Integrated Dose (2) Normal	Integrated Dose (2) Accident
Above Core *(Zone 1)	Gamma Neutron	25.0 5×10^4	*LOCA	1.3×10^6	8.8×10^6 6.3×10^{13}	2.6×10^7
Core Region * (Zone 2)	Gamma Neutron	50.0 1.4×10^5	*LOCA	1.3×10^6	1.8×10^7 1.8×10^{14}	2.6×10^7
Under Vessel *(Zone 3)	Gamma Neutron	7.2 < 1	*LOCA	1.3×10^6	2.5×10^6 1.3×10^9	2.6×10^7
Near Recirc. Pumps *(Zone 4)	Gamma Neutron	25.0 2×10^3	*LOCA	1.3×10^6	8.8×10^6 2.5×10^{12}	2.6×10^7

II. Containment (Outside Drywell)

Equipment or Area	Radiation Type	Operating Dose Rate (1)	Design Basis Accident Type	Design Basis Accident Dose Rate (1)	Integrated Dose (2) Normal	Integrated Dose (2) Accident
Suppression Pool *(Zone 6)	Gamma Neutron	0.1 2×10^2	*LOCA	1.3×10^6	3.5×10^4	2.6×10^7
General Floor Area	Gamma	0.001	*LOCA	6.5×10^2	3.5×10^2	1.7×10^5

Table 2 (continued)

RADIATION ACCIDENT CONDITIONS -- GRAND GULF BWR/6 MARK III

II. Containment (Outside Drywell) (Cont.)

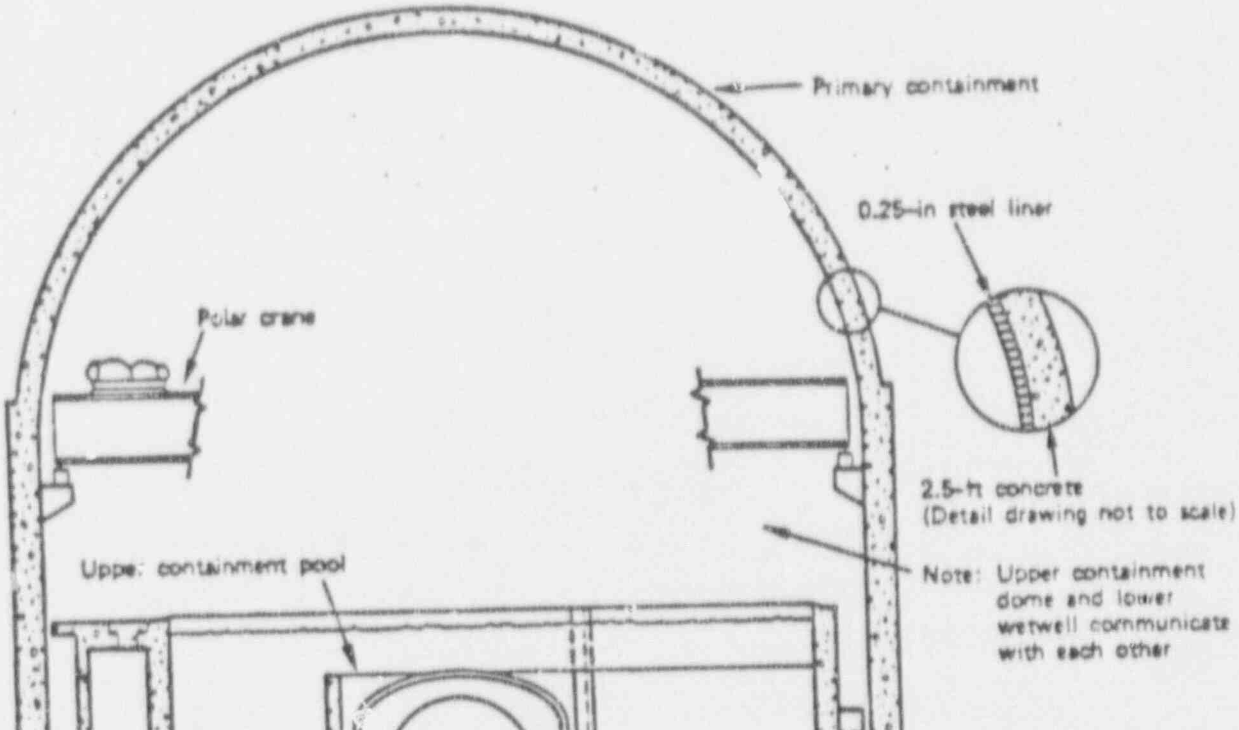
Equipment or Area	Radiation Type	Operating Dose Rate (1)	Design Basis Accident Type	Design Basis Accident Dose Rate (1)	Integrated Dose (2) Normal	Integrated Dose (2) Accident
24-in. Pipe Containing Suppression Pool Water (Typical Pipe)	Gamma	Negligible	*LOCA	1.4×10^4	0.0	7.9×10^5
Cleanup Systems						
a) Heat Exchanger	Gamma	15.0	*LOCA	6.5×10^2	8.76×10^6	1.7×10^5
b) Filters & Tanks	Gamma	10.0	*LOCA	6.5×10^2	3.6×10^6	1.7×10^5

Table 2 (continued)

RADIATION ACCIDENT CONDITIONS -- GRAND GULF BWR/6 MARK III

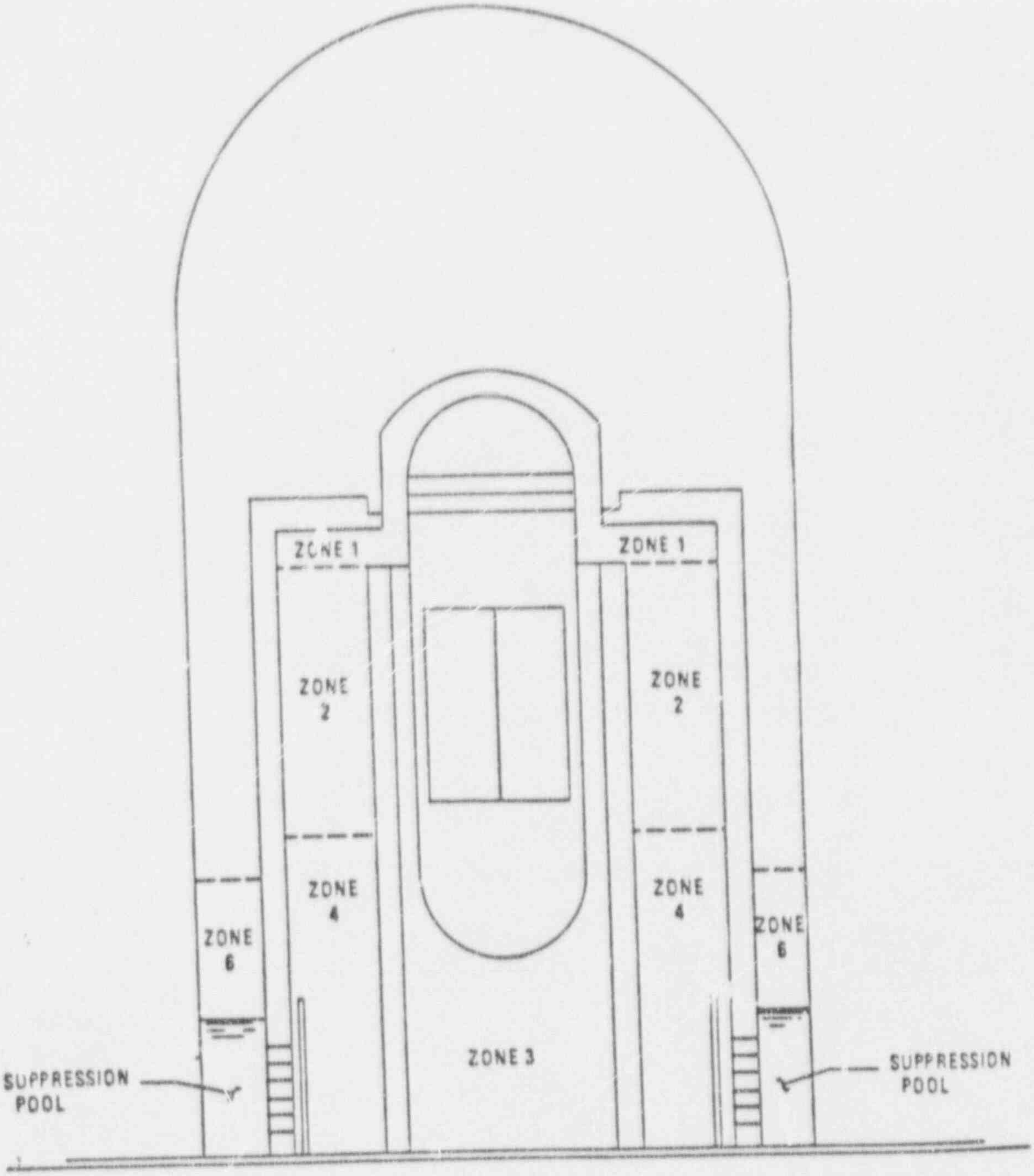
III. Auxiliary Building

Equipment or Area	Radiation Type	Operating Dose Rate (1) Plant Oper	System Oper	Design Basis Accident Type	Dose Rate (1)	Integrated Dose (2) Normal	Accident
HPCS and RCIC Area	Gamma	0.015	0.200	*LOCA	$1.6x10^2$	$5.3x10^3$	$4.5x10^4$
RHR and LPCS Area	Gamma	0.015	0.030	*LOCA	$1.6x10^2$	$5.3x10^3$	$4.5x10^4$
Steam Tunnel	Gamma	5		*LOCA Rod Drop	$1.6x10^2$ $2.5x10^2$	$1.8x10^6$	$4.5x10^4$ $2.5x10^2$
Standby gas treatment system	Gamma	0.001		*LOCA	$5.7x10^5$		$3.8x10^4$



Mark III containment.

Figure 2



MISSISSIPPI POWER & LIGHT COMPANY GRAND GULF NUCLEAR STATION UNITS 1 & 2 FINAL SAFETY ANALYSIS REPORT	DRYWELL RADIATION ZONES FIGURE 3.11-1

Figure 3

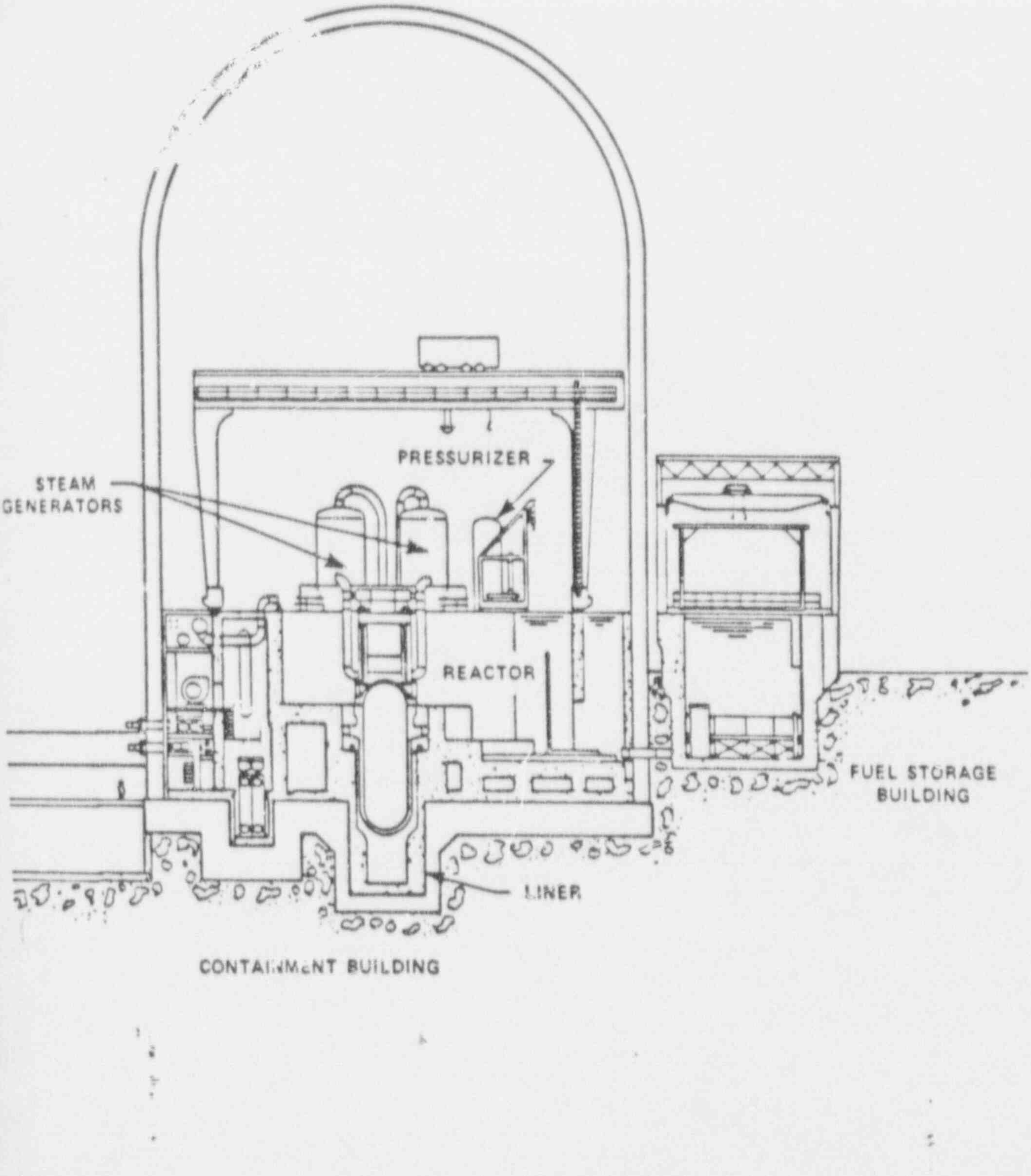


Figure 4 Cross Section of a Typical PWR Plant

Table 3 (From WCAP - 8587, Rev 5)

40 YEAR NORMAL OPERATING DOSES - INSIDE CONTAINMENT

Location	γ Dose rate R/hr	40 yr γ dose (R)
RCL pipe center	820	3.0×10^8
RCL pipe ID	470	1.6×10^8
RCL pipe OD (contact)	165	5.8×10^7
RCL - general area	50	$<2.0 \times 10^7$
Outside loop compartment wall	<0.1	$<3.5 \times 10^4$
Detectors located next to R.V.	5×10^4	1.8×10^{10} (a)

(a) 40 year dose from neutrons > 1 Mev is 5×10^{18} n/cm^2.

TABLE 6-3

40 YEAR NORMAL OPERATING DOSES - OUTSIDE CONTAINMENT

Location	40 yr γ dose (R)
Penetration Area	$<1 \times 10^6$
Pump Cubicles	
Radioactive Waste Area	
Radwaste Tank Cubicles	$<1 \times 10^7$
Other general areas	$<4 \times 10^2$

Table

RADIATION ACCIDENT CONDITIONS -- LIMERICK BWR/4 MARK II

TABLE 1a

CALCULATED PRIMARY CONTAINMENT DOSE RATES

Gamma Dose Rates

TIME INT. HRS	DOSE RATE R/HR	INT. DOSE RADS	TOTAL RADS
.10E-01	1.07E+07	.00	.00
.50E+00	3.51E+06	3.16E+06	3.16E+06
.10E+01	2.60E+06	1.52E+06	4.68E+06
.20E+01	1.85E+06	2.20E+06	6.88E+06
.40E+01	1.23E+06	3.04E+06	9.92E+06
.80E+01	7.10E+05	3.79E+06	1.37E+07
.16E+02	3.66E+05	6.15E+06	1.79E+07
.24E+02	2.61E+05	2.39E+06	2.03E+07
.96E+02	7.17E+04	1.01E+07	3.03E+07
.24E+03	3.63E+04	7.32E+06	3.76E+07
.72E+03	6.37E+03	7.00E+06	4.46E+07
.22E+04	2.56E+01	1.22E+06	4.58E+07
.63E+04	6.56E+00	3.02E+04	4.59E+07

Beta Dose Rates

TIME INT. HRS	DOSE RATE R/HR	INT. DOSE RADS	TOTAL RADS
.10E-01	1.30E+08	.00	.00
.50E+00	4.48E+07	3.92E+07	3.92E+07
.10E+01	3.56E+07	2.00E+07	5.92E+07
.20E+01	2.68E+07	3.10E+07	9.02E+07
.40E+01	1.88E+07	4.51E+07	1.35E+08
.30E+01	1.26E+07	6.20E+07	1.97E+08
.16E+02	8.00E+06	8.10E+07	2.78E+08
.2[illegible]E+02	5.92E+06	5.53E+07	3.34E+08
.96E+02	3.22E+06	2.72E+08	6.05E+08
.24E+03	1.01E+06	2.21E+08	8.26E+08
.72E+03	1.25E+05	2.03E+08	1.03E+09
.22E+04	3.00E+04	9.59E+07	1.13E+09
.63E+04	1.87E+04	5.16E+07	1.18E+09

TABLE 1c

CALCULATED SECONDARY CONTAINMENT DOSE RATES

Gamma Dose Rates

TIME INT. HRS	DOSE RATE R/HR	INT. DOSE RADS	TOTAL RADS
.10E-0[illegible]	1.00E-10	.00	.00
.50E+00	2.49E+03	4.36E+00	4.36E+00
.10E+01	3.23E+03	1.42E+03	1.46E+03
.20E+01	3.93E+03	3.57E+03	5.03E+03
.40E+01	4.55E+03	8.47E+03	1.35E+03
.8CE+01	4.46E+03	1.80E+03	3.15E+03
.24E+02	3.07E+03	5.96E+03	9.11E+03
.96E+02	1.87E+03	1.74E+04	2.65E+04
.24E+03	9.33E+01	1.94E+04	4.59E+04
.72E+03	6.40E+00	1.56E+04	6.15E+04
.63E+04	5.78E-02	4.85E+03	6.63E+04

Beta Dose Rates

TIME INT. HRS	DOSE RATE R/HR	INT. DOSE RADS	TOTAL RADS
.10E-09	1.00E-10	.00	.00
.50E+00	9.40E+02	1.57E+01	1.57E+01
.10E+01	1.39E+03	5.75E+02	5.91E+02
.20E+01	1.92E+03	1.64E+03	2.23E+03
.40E+01	2.50E+03	4.41E+03	6.64E+03
.80E+01	3.03E+03	1.10E+04	1.77E+04
.24E+02	3.30E+03	5.22E+04	6.99E+04
.96E+02	3.35E+03	2.47E+05	3.16E+05
.24E+03	1.75E+03	3.55E+05	6.71E+05
.72E+03	2.01E+03	3.44E+05	1.01E+06
.63E+04	6.23E+01	3.66E+05	1.38E+06

GAMMA DOSE AND DOSE RATE INSIDE CONTAINMENT (LOCA)
(FROM WCAP-8587, REV. 5, APRIL 1982)

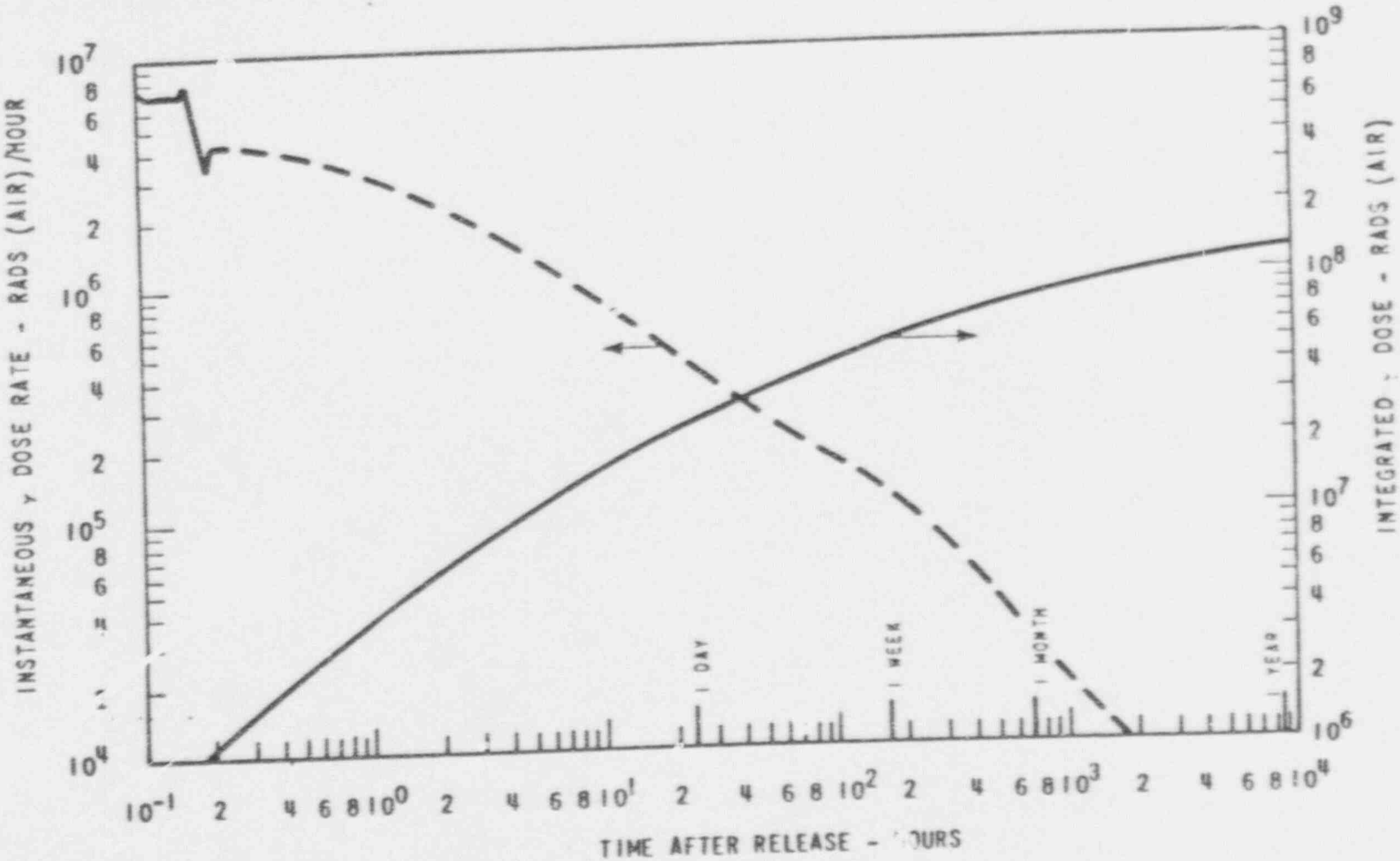


Figure 5

BETA DOSE AND DOSE RATE INSIDE CONTAINMENT (LOCA)
(FROM WCAP-8587, REV. 5, APRIL 1982)

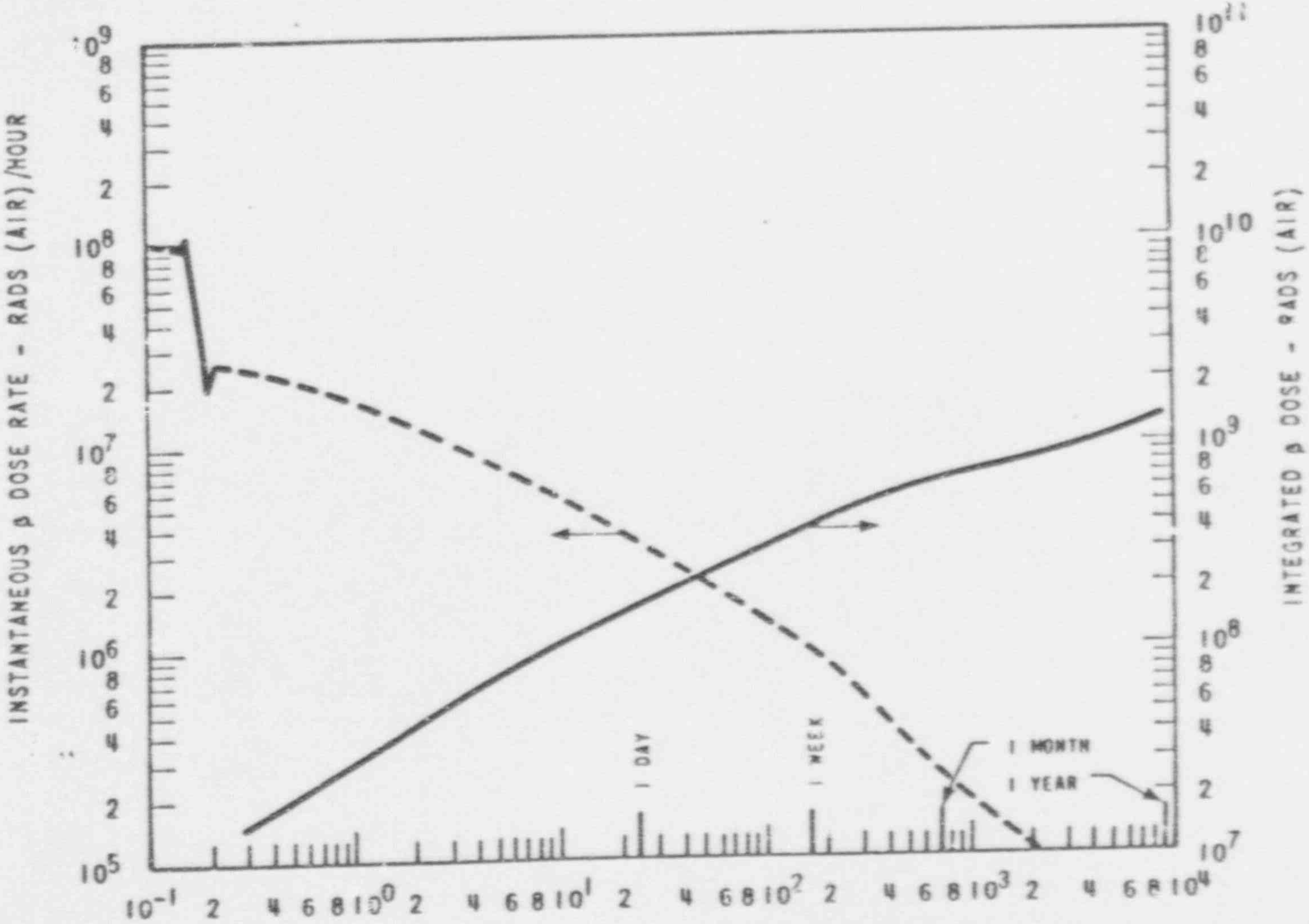


Figure 6

GAMMA DOSE AND DOSE RATE INSIDE CONTAINMENT (STEAM LINE BREAK)
(FROM WCAP-8587, REV. 5, APRIL 1982)

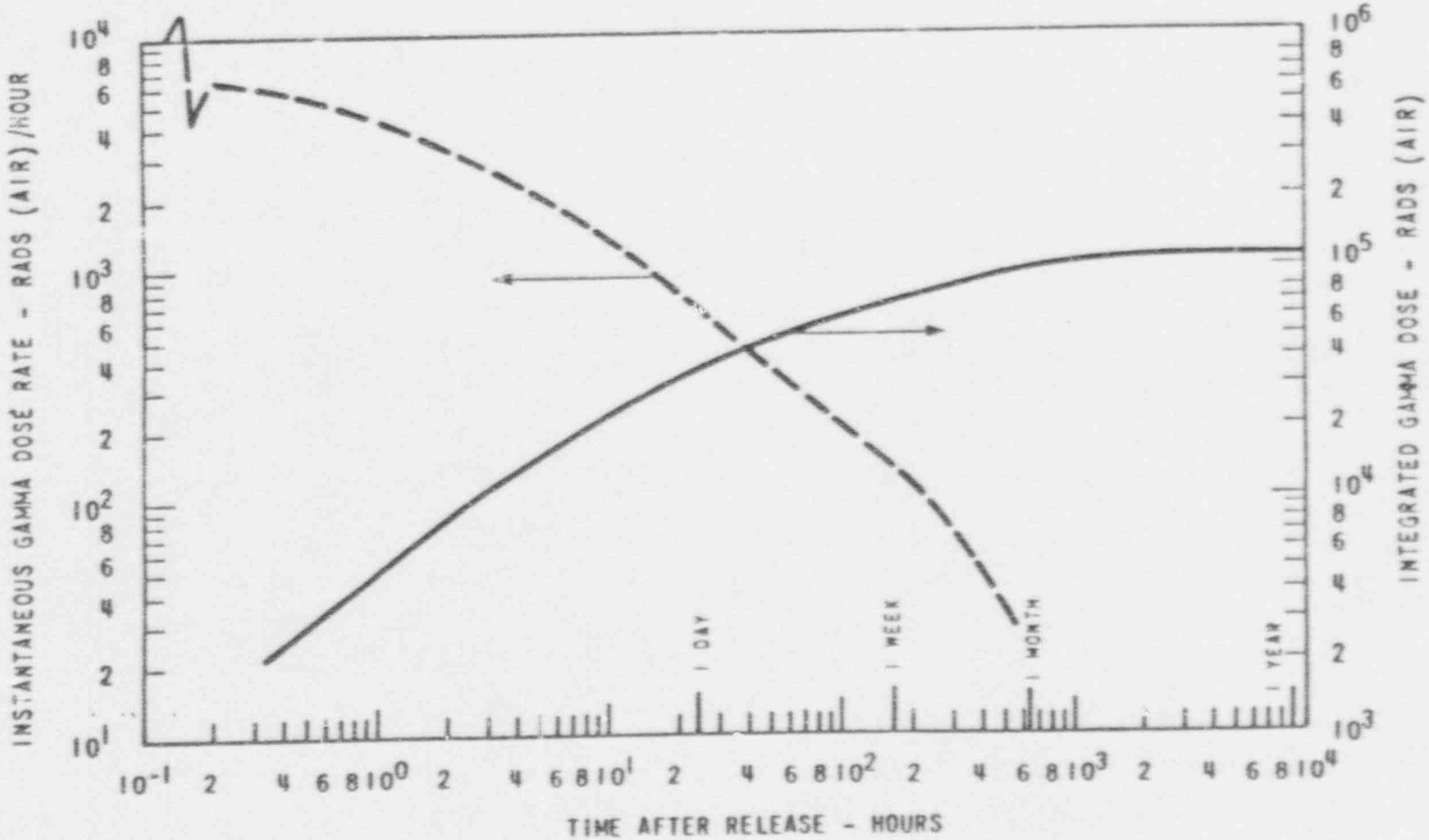


Figure 7

BETA DOSE AND DOSE RATE INSIDE CONTAINMENT (STEAM LINE BREAK)
(FROM WCAP-8587, REV. 5, APRIL 1982)

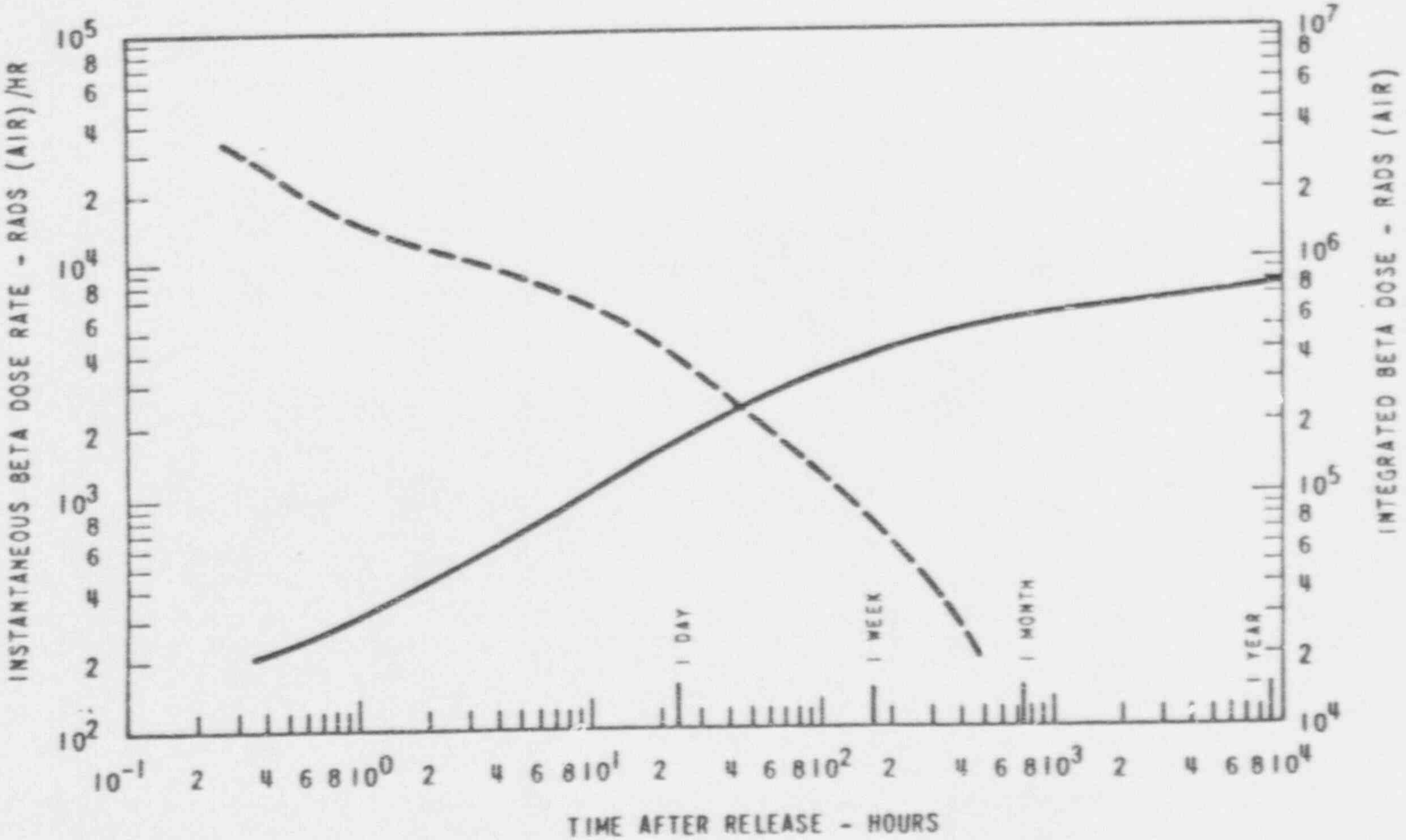


Figure 8

TABLE 5

NORMAL PLANT OPERATIONAL ENVIRONMENTAL CONDITIONS for Grand Gulf

Area	Pressure (as noted)	Temperature (F) Normal (2)	Relative humidity % Min/Max
I. Inside drywell			
A. Area above reactor vessel shield to top of drywell	-0.5 to +2.0 psig	135	40/60
B. Region adjacent to core	"	"	"
C. Under RPV, inside shield wall	"	112	"
D. Vicinity of recirculation pump motors	"	135	"
II. Containment			
A. Area above suppression pool	-1.0 to -0.10 in. wg	80	60
B. General floor area	"	"	"
C. Main steam line tunnel	"	125	30/90
D. Reactor water cleanup system 1. Heat exchangers 2. Filters and tanks	"	105	30/90

040.3

TABL 5 (Cont.)

040.3

Area	Pressure (as noted)	Temperature (F) Normal (2)	Relative humidity % Min/Max
III. Auxiliary Building			
A. RHR eqmt rooms	Atmos $\pm$1.0 in. wg	105 (1)	30/90
B. HPCS eqmt room	"	"	"
C. RCIC eqmt room	"	" (1)	"
D. LPCS eqmt room	"	"	"
E. SGTS room	"	"	"
F. Pipe penetration rooms	"	"	"
G. Electrical Penetration Rooms	"	104	30/90
H. Purge and ventilation rooms	"	105	"
I. Drain pump rooms	"	"	"
J. CCW pump and heat exchanger room	"	80	"
K. CRD pumps and filter room	"	"	"
L. CRD repair room	"	"	"
M. Fuel pool eqmt room	"	"	"
N. Fuel pool demineralizer rooms	"	"	"
O. Fuel handling area fan room	"	"	"

TABLE 5 (Cont.)

Area	Pressure (as noted)	Temperature (F) Normal (2)	Relative humidity % Min/Max
P. Fuel handling area	"	"	"
Q. All other areas	"	"	50
R. Vicinity of Steamlines	"	125	30/90
IV. Control Building			
A. Control room	1/4 in. + 1/4 in. wg	72	40/50
B. Other rooms containing batteries, switchgear, cables, etc. having safety-related functions	"	104	30/90
V. Other Areas			
A. Diesel generator areas	"	80	30/90
B. Outdoor areas	--	95 max	--
C. Turbine Building	"	105 max	50

040.3

25

NOTE

1. 150 F during hot standby and plant shutdown
2. Minimum temperature inside the plant structures containing safety-related equipment will be 65 F or greater with an outside temperature of 20 F.

040.3

Table 6

TABLE 5-1

NORMAL AND ABNORMAL OPERATING ENVIRONMENTS

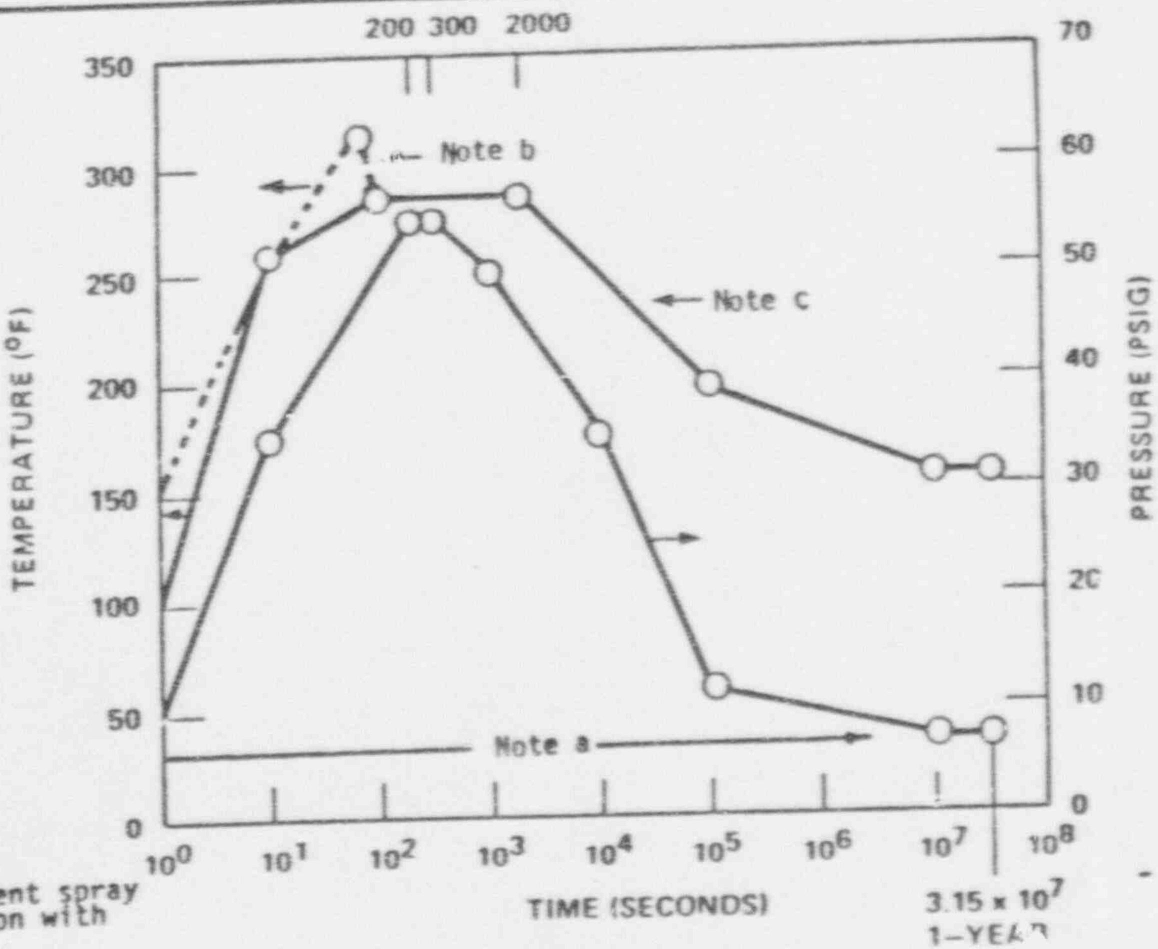
General Area	Zone Description	Zone Code	Typical Areas	Range	Normal Operation Temp (°F)	Normal Operation RH (%)	Normal Operation Press. (psig)	Abnormal Operation Time Limit	Abnormal Operation Temp (°F)	Abnormal Operation RH (%)	Abnormal Operation Press. (psig)
In-Containment	Inaccessible	IC/I	Inside Sec. Shield	Max	135	70	+0.3	8 hours	[illegible]	95	Atmos
				Min	65	20	-0.1		50	0	Atmos
	Accessible	IC/O	Outside Sec. Shield	Max	120	70	+0.3	–	120	95	Atmos
				Min	65	20	-0.1		50	0	Atmos
									82	95	
Out of Containment	Air Conditioned[a]	OC/A.C.	Control room, Aux Equip Room	Max	80	50	Atmos	12 hrs	120	35	Atmos
				Min	60	30	Atmos		40	0	Atmos
									82	95	
	Ventilated	OC/V	Aux building, Safeguards	Max	104	70	Atmos	12 hrs	120	35	Atmos
				Min	60	20	Atmos		40	0	Atmos
									82	95	
	Non-Ventilated	OC/NV	Turbine-Hall	Max	104	70	Atmos	–	120	35	Atmos
				Min	60	20	Atmos		40	0	Atmos

Note a: Abnormal operating parameters only apply for applications whe.e Class 1E air conditioning systems are not supplied.

From WCAP 8587, Rev 5, April, 1982

Figure 9

WCAP-8587 PWR CONTAINMENT LOCA DESIGN CONDITIONS



Note a: Initial 24 hour containment spray solution of 2500 ppm boron with 0.24% NaOH

Note b: Represents plants whose analysis predicts super heated conditions

Note c: Represents plants whose analysis does not predict super heated conditions

Figure 10

WCAP-8587 PWR CONTAINMENT MSLB CONDITIONS

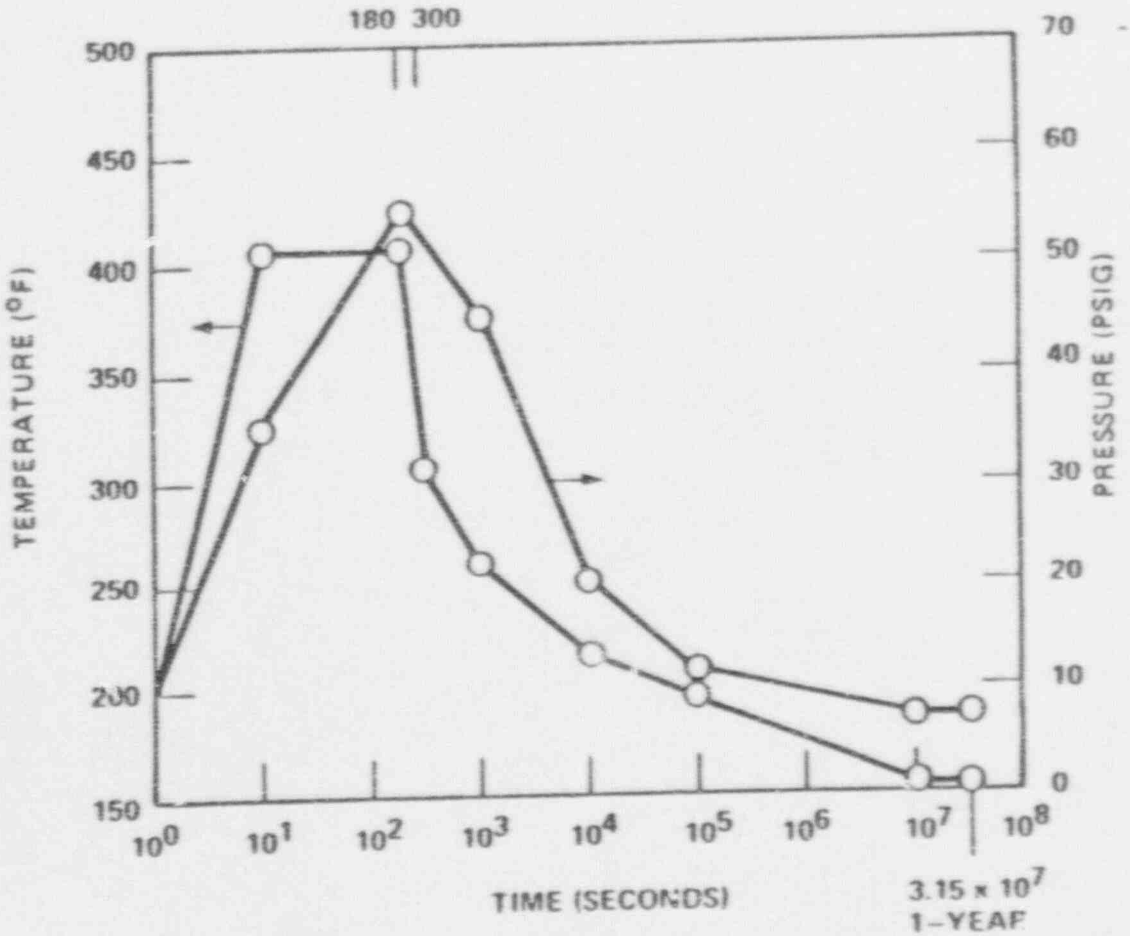


Figure 11

LIMERICK BWR/4 MARK II ACCIDENT ENVIRONMENTAL PROFILE

LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION 8031-M-171

CALCULATED
BOUNDING DRYWELL
TEMPERATURE PROFILE
FOLLOWING A LARGE-BREAK LOCA

— Primary Containment

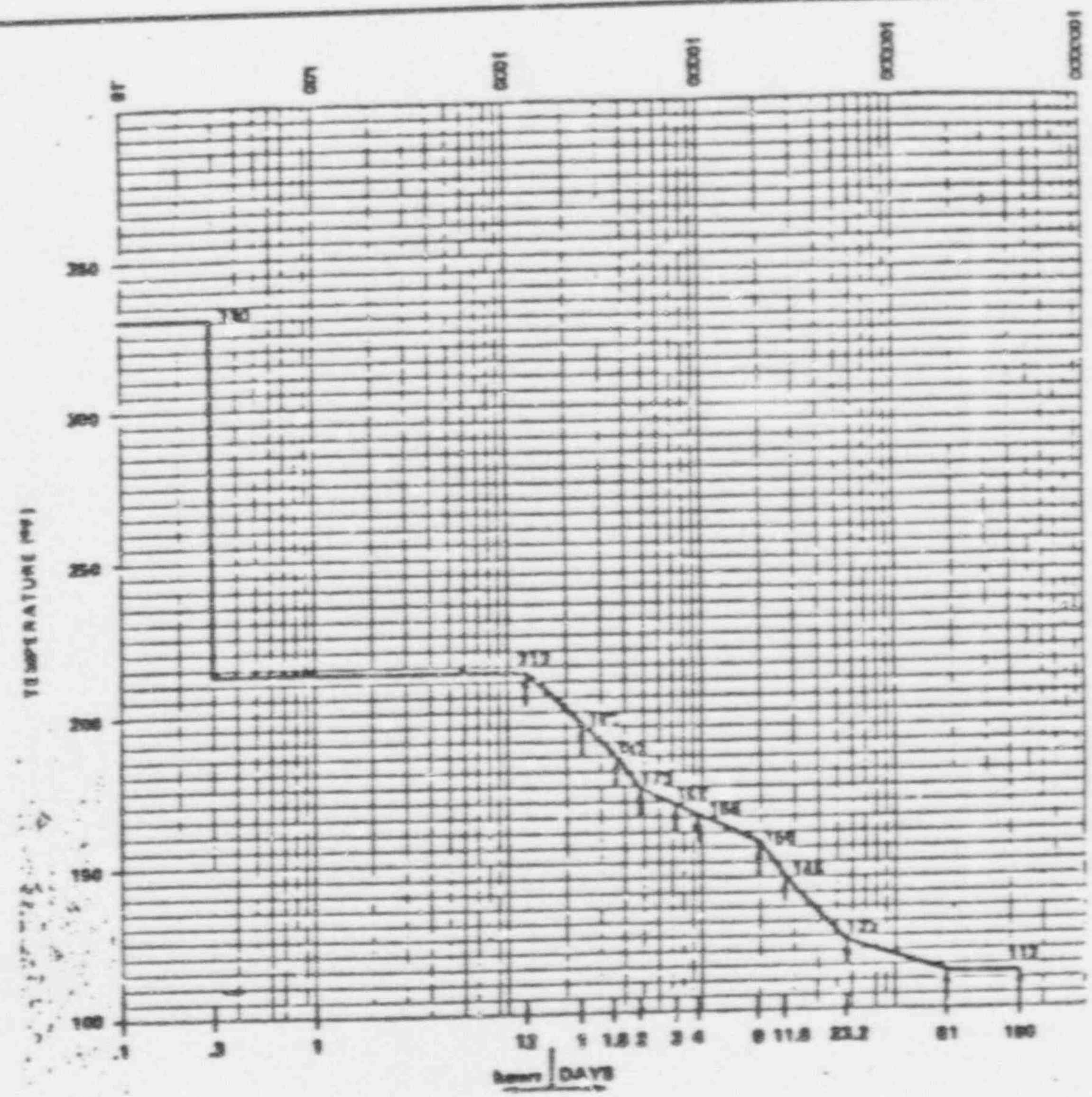


Figure 12

LIMERICK BWR/4 MARK II ACCIDENT ENVIRONMENTAL PROFILE

LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION 8031-M-171

CALCULATED
BOUNDING DRYWELL
TEMPERATURE PROFILE
FOLLOWING A SMALL-BREAK LOCA

FIGURE 30 | 30 | REV. 2

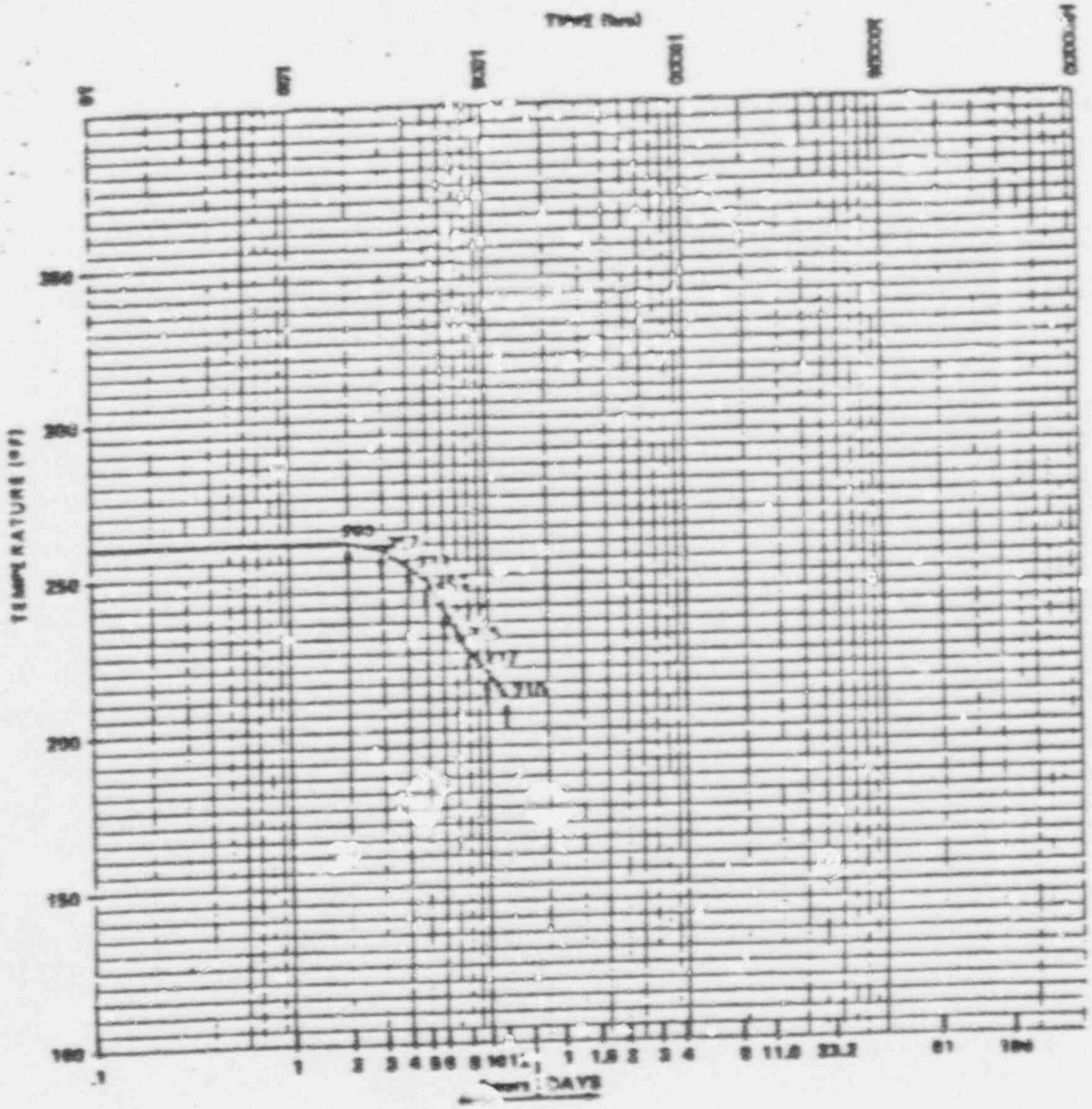


Figure 13

LIMERICK BWR/4 MARK II ACCIDENT ENVIRONMENTAL PROFILE

LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION 8031-M-171

CALCULATED
BOUNDING DRYWELL
TEMPERATURE PROFILE

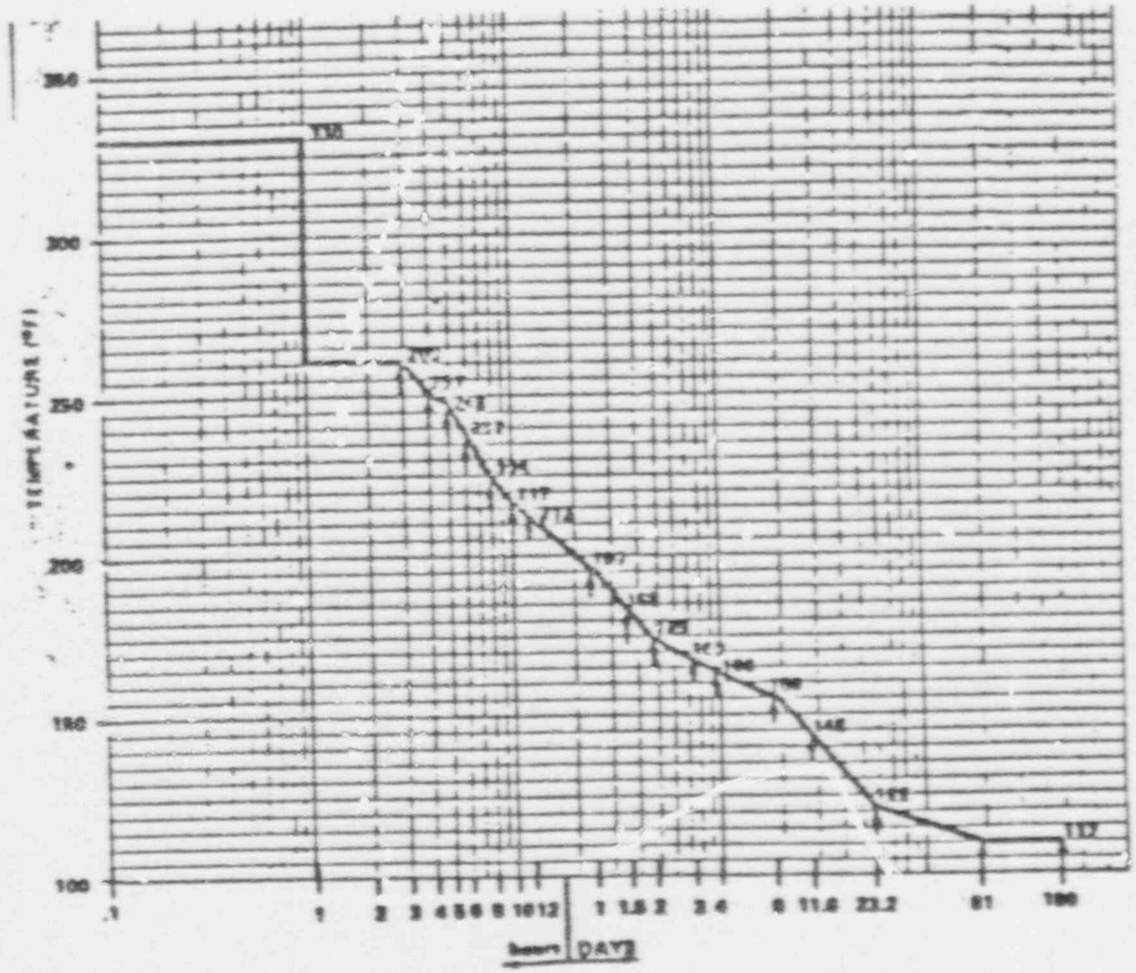
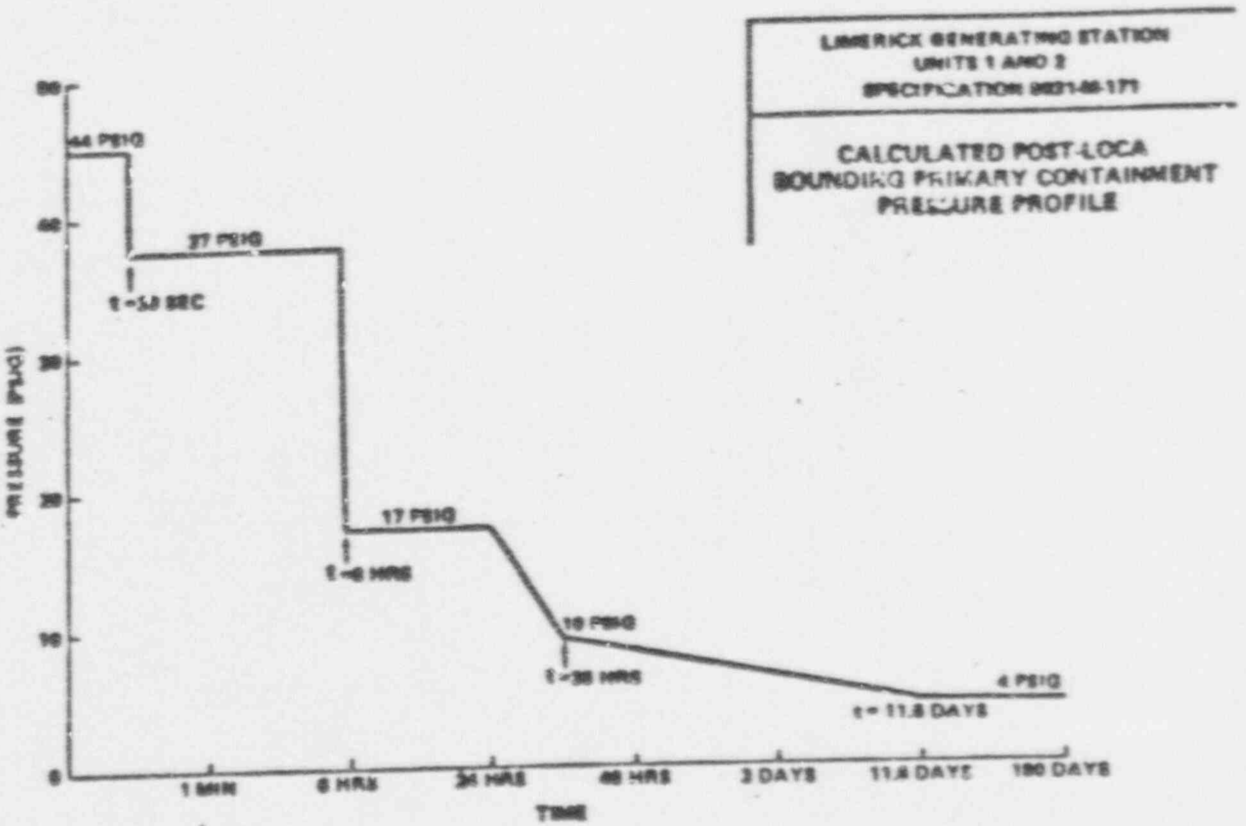


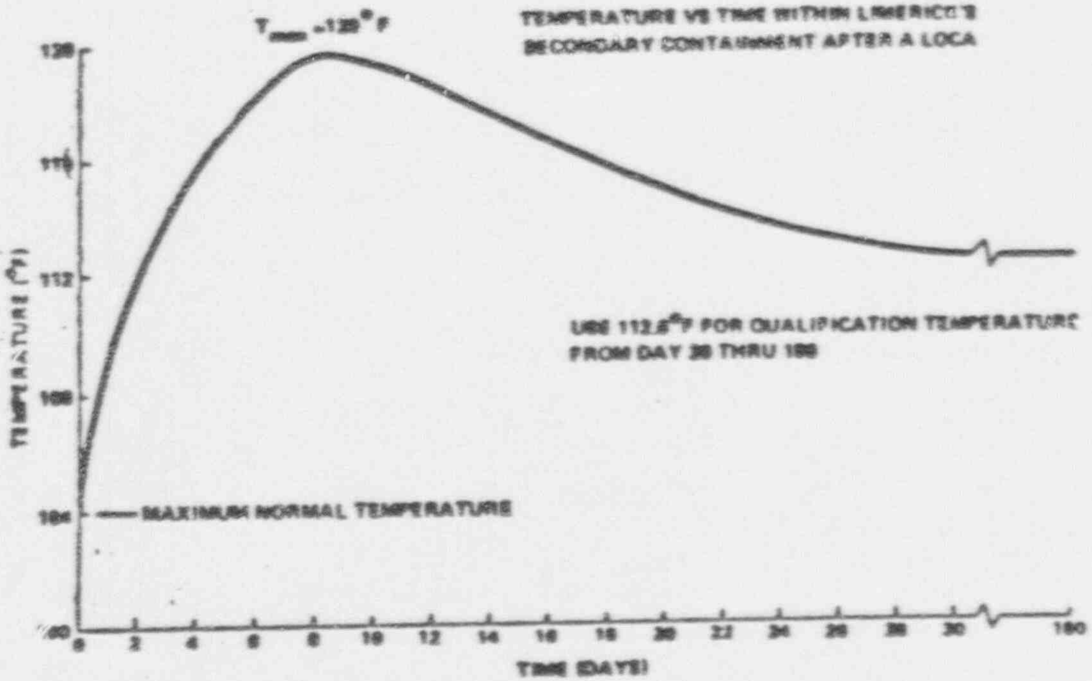
Figure 14

LIMERICK BWR/4 MARK II ACCIDENT ENVIRONMENTAL PROFILE



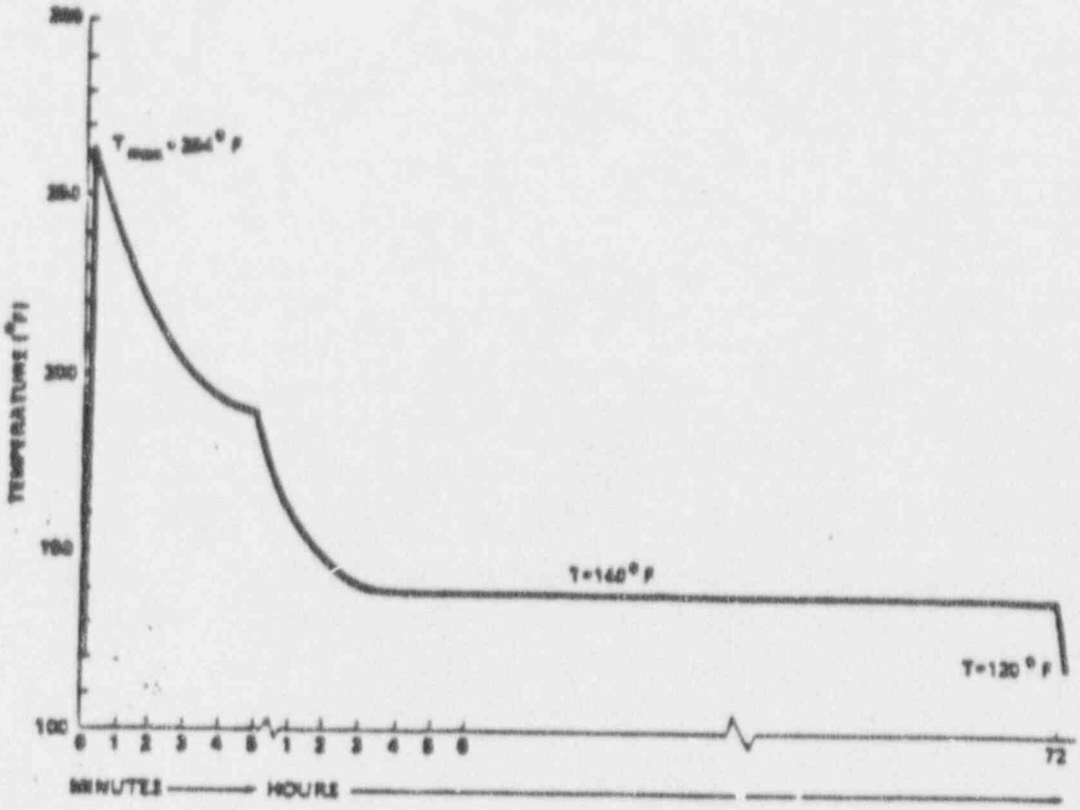
Figure

LIMERICK BWR/4 MARK II ACCIDENT ENVIRONMENTAL PROFILE



LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION

CALCULATED
REACTOR ENCLOSURE LOCA
TEMPERATURE PROFILE



LIMERICK GENERATING STATION
UNITS 1 AND 2
SPECIFICATION 8031-06-171

ISOLATION VALVE COMPARTMENT
(EL 217') HELB TEMPERATURE PROFILE

FIGURE 7 — -88- — REV. 0

Figure 16

Margin

10 CFR 50.49 indicates that " margins must be applied to account for unquantified uncertainty, such as the effects of production variations and in- curacies in test instruments. These margins are in addition to any conservations applied during the derivation of local environmental conditions of the equipment unless these conservatisms can be quantified and shown to contain appropriate margins.

Reg Guide 1.89 (revision 1, June, 1984) provides additional guidance regarding the 10 CFR 50.49 requirements. It states:

4. The suggested values in Section 6.3.1.5, "Margin," of IEEE Std 323-1974, except time margins, are acceptable for meeting the requirements of paragraph 50.49(e)(8). Alternatively, quantified margins should be applied to the environmental parameters discussed in Regulatory Position C.2 to ensure that the postulated accident conditions have been enveloped during testing. These margins should be applied in addition to any conservatism applied during the derivation of local environmental conditions of the equipment unless these conservatisms can be quantified and shown to contain appropriate margins. The margins should account for variations in commercial production of the equipment and the inaccuracies in the test equipment.

Some electric equipment may be required by the design to perform its safety function only within the first ten hours of the event. This equipment should remain functional in the accident environment for a period of at least 1 hour in excess of the time assumed in the accident analysis unless a time margin of less than one hour can be justified. This justification must include, for each piece of equipment, (1) consideration of a spectrum of breaks, (2) the potential need for the equipment later in an event or during recovery operations, (3) a determination that failure of the equipment after performance of its safety function will not be detrimental to plant safety or mislead the operator, and (4) a determination that the margin applied to the minimum operability time, when combined with the other test margins, will account for the uncertainties associated with the use of analytical techniques in the derivation of environmental parameters, the number of units tested, production tolerances, and test equipment inaccuracies. For all other equipment (e.g., postaccident monitoring, recombiners), the 10% time margin identified in Section 6.3.1.5 of IEEE Std 323-1974 should be used.

Note that Reg Guide 1.89's guidance includes a one hour minimum operability recommendation. For other parameters, the reg guide indicates that the suggested values for margin contained in IEEE Std. 323-1974 are acceptable.

IEEE Std. 323-1974 and 323-1983 provide guidance regarding margin. The 1983 version changes the recommendation for environmental transient margin, clearly states that margin is not meant to be applied to aging, and states that "in all cases engineering judgement should used to determine the adequacy". The 323-1983 version also fails to endorse the one hour minimum operability requirement that was first mentioned by the NRC in NUREG-0588 (December, 1979). IEEE Std. 323-1974's statement concerning margin is as follows:

> 6.3.5 *Margin*. Margin is the difference between the most severe specified service conditions of the plant and the conditions used in type testing to account for normal variations in commercial production of equipment and reasonable errors in defining satisfactory performance. The qualification type testing shall include provisions to verify that adequate margin exists. In defining the type test, increasing levels of testing, number of test cycles, and test duration shall be considered as methods of assuring adequate margin does exist.
>
> Suggested factors to be applied to service conditions for type testing are as follows:
>
> (1) Temperature: + 15°F (8°C). When qualification testing is conducted under saturated steam conditions, the temperature margin shall be such that test pressure will not exceed saturated steam pressure corresponding to peak service temperature by more than 10 lb_f/in^2
>
> (2) Pressure: + 10 percent of gauge, but not more than 10 lb_f/in^2 [$7.03(10^{-1})$ kg/cm^2]
>
> (3) Radiation: + 10 percent (on accident dose)
>
> (4) Voltage: ± 10 percent of rated value unless otherwise specified
>
> (5) Frequency: ± 5 percent of rated value unless otherwise specified
>
> (6) Time: + 10 percent of the period of time the equipment is required to be operational following the design basis event
>
> (7) Environmental Transients: The initial transient and the dwell at peak temperature shall be applied at least twice
>
> (8) Vibration: + 10 percent added to the acceleration of the response spectrum at the mounting point of the equipment
>
> NOTE: Negative factors shall be applied when lowering the value of the service conditions increases the severity of the test.

IEEE Std. 323-1983's statement regarding margin is as follows:

6.3.1.5 Margin. Margin shall be applied to the type test parameters for DBE testing. Specific equipment qualification standards provide guidelines on margin. However, for cases where no margins are given, the following suggested factors may be used. These are only suggested factors and should be reviewed for each application. In some cases, lesser values will be adequate while in others larger values may be necessary. In all cases, engineering judgment should be used to determine the adequacy.

(1) Peak temperature: + 15 °F (8 °C). When qualification testing is conducted under saturated steam conditions, the temperature margin shall be such that test pressure will not exceed saturated steam pressure corresponding to peak service temperature by more than 10 lbf/in².

(2) Peak pressure: + 10% of gage, but not more than 10 lbf/in², 7.03 (10^{-1})kg/cm², or at a gage pressure of 68.948 kPa

(3) Radiation: + 10% (on accident dose)

(4) Power supply voltage: ± 10% but not to exceed equipment design limits

(5) Line frequency: ± 5% of rated value

(6) Equipment operating time: + 10% of the period of time the equipment is required to be operational following the start of the DBE

(7) Seismic vibration: + 10% added to the acceleration requirements at the mounting point of the equipment.

For environmental transients, two methods which may be used to apply margin are: (1) temperature and pressure margin may be added or (2) the peak transient without temperature and pressure margin may be applied twice. Combinations of these or other methods may also be used.

Margin may be positive or negative in accordance with what increases the severity of the test. For example, it will generally be necessary to increase temperature, while in the case of equipment supply voltage given as a nominal value, it may be necessary to use either increasing or decreasing values.

The margin factors suggested above are not meant to be applied to aging. Natural aging (see 6.3.3.1) by its nature, does not require margin. For age conditioning (see 6.3.3.2), use conservative practices in simulating aging effects; that is, age conditioning shall be performed on the basis of conservative estimates of service conditions and conservative accelerated aging techniques.

One obtains qualification specifications by adding margin to quipment environmental specifications. From the standpoint of .C inspections there are several things to be aware of:

1. Purchase specifications may indicate to a manufacturer that environmental profiles in the purchase specification already include adequate margin.

2. IEEE Std. 323-1974, Appendix A includes a "Test Chamber Temperature Profile for Environmental Simulation (Combined PWR/BWR)". For lack of a better standard profile, numerous manufacturers have employed this profile for their qualification tests. Reg Guide 1.89 has a definite opinion regarding the IEEE Std. 323-1974 profile. It states:

> "Since the test profiles included in Appendix A to IEEE Std 323-1974 are only representative, they should not be considered an acceptable alternative to using plant-specific containment temperature and pressure design profiles unless plant-specific analysis is provided to verify the applicablity of those profiles."

3. IEEE Std. 382-1980 presents specific qualification profiles to be employed during qualification of safety-related valve actuators. These profiles may be too severe for some plant applications. Rumor suggests that the bounding conditions for PWR applications is based on an unsold PWR design.

POSSIBLE ENVIRONMENTS DURING THE OPERATIONAL LIFE OF SAFETY-RELATED EQUIPMENT

THE AGING ENVIRONMENT (≤ 40 YR)

SIMULTANEOUS EXPOSURE TO:

- LOW LEVEL RADIATION
- TEMPERATURE
- HUMIDITY, DUST
- VIBRATION
- CYCLING (OPERATIONAL)

THE ACCIDENT ENVIRONMENT

SIMULTANEOUS EXPOSURE TO:

- RADIATION (BETA AND GAMMA)
- STEAM
- CHEMICAL SPRAY
- SUBMERGENCE (SOMETIMES)
- FUNCTIONABILITY REQUIREMENTS

TIME

Figure 17

5. Must the effects of mechanical cycling be considered in the aging program? Can the mechanical cycling requirements be reduced?

*Accident Questions

1. Should the accident simulation account for radiation dose rate effects?

2. How does one simulate beta and gamma radiation environments? How do you account for beta shielding effects?

3. Are there accident synergistic effects?

4. Is oxygen presence during an accident simulation important?

5. Is the steam ramp time important?

6. Can saturated steam conditions be employed instead of superheated steam?

7. What test considerations are relevant for chemical spray?

8. What are relevant post-accident acceleration techniques?

9. Must submergence be considered in the accident simulation?

We will now start answering these questions. Both regulatory and technical issues will be discussed. In some cases a strong regulatory position has not yet been formulated. Many times this reflects an inadequate technical basis. Let us begin with the first question.

Must the same piece of equipment be exposed to all portions of the sequential exposure?

Testing of the same prototype to both environmental and sesmic stresses is not required. In its prologue to 10 CFR 50.49 the NRC indicates "The Commission has decided, after considerable deliberation, to pursue the issue of seismic and dynamic qualification separately at a future date" 10 CFR 50 49, section c states that requirements for dynamic and seismic qualification of electric equipment important to safety is not part of 10 CFR 50.49.

Neither 10 CFR 50.49 nor Reg Guide 1.89 (revision 1, June, 1984) clearly state that the same protype must be used during all portions of the sequential qualification exposure. Earlier NRC positions indicated that the same protype was to be employed. For example, the DOR Guidelines state:

"The same test specimen should be used throughout the test sequence for all service conditions the equipment is to be qualified for by type testing. The type test should only be considered valid for the service conditions applied to the same test specimen in the appropriate sequence."

Similarly, Section 2.3(1) of NUREG-0588 states:

"The test prodedures should insure that the same piece of equipment is used throughout the test sequence, and that the test simulates as closely as practicable the postulated accident environment."

The Appendix to NUREG-0588 further clarifies this issue in response to comment 66. The staff basically agrees that performance requirements during normal operation can be established via separate protypes than those used for accident simulation tests. However, the staff asserts that when exposing equipment to hostile environments, the same piece of equipment should be used.

Replacement of equipment subcomponents during a test sequence is something you may run into during an inspection. There are two possibilities:

1. During the aging simulation, components such as O-rings or gaskets are replaced at pre-defined intervals as established by the test plan. This test procedure should be correlated with maintenance practices for that device. For example, maintenance requirements may specify that gaskets and O-rings for a transmitter be replaced every 5 years. Thus during the 40 year aging simulation it would be acceptable to replace the gaskets and O-rings on a periodic basis. However, for this example, O-rings and gaskets should be aged to their most severe condition for a 5 year life. During an inspection check to insure that maintnenace requirements assumed by the test strategy are clearly identified in the test plan and test report.

2. During the aging and/or accident simulation a subcomponent may fail. The test laboratory may decide to replace the subcomponent with an identical subcomponent (arguing that a random failure occurred) or may elect to install a new subcomponent design and continue the test. We have experienced both of these situations during NRC inspections. Some things to look for in this situation:

   a. Was the replacement subcomponent properly aged? Are there adequate aging records, etc?

   b. Was a thorough failure analysis performed that clearly established the random nature of the failure?

   c. Was more than one component tested?

At what portions of the sequential exposure must functional performance be demonstrated?

Reg Guide 1.89 (revision 1, June, 1983) clearly states:

"Performance characteristics that demonstrate the operability of equipment should be verified before, after, and periodically during testing throughout the range of required operability."

We will be discussing functional performance requirements later in this course.

How can the thermal aging environment be accelerated?

The first thing we must discuss is the purpose of accelerated aging. There are two possibilities:

1. To rigorously place a piece of equipment in the condition one would expect at its end of installed life (typically 40 years).

2. To probe or qualitatively assess the vulnerability of equipment to aging effects and not to achieve aging in the strict sense.

The second purpose is the most realistic purpose of accelerated aging. It also appears to be NRR's intent. However it is rather difficult to write NRC requirements or guidance that suggest the second purpose which are also inspectable. Hence, many NRC aging requirements are written in the style of the first purpose with the stated understanding that there are state-of-the-art limitations to what is achievable. For example, 10 CFR 50.49 states that:

"Equipment qualified by test must be preconditioned by natural or artificial (accelerated) aging to its end-of-installed life condition."

Reg Guide 1.89 expands on this requirement. It states :

"The Arrhenius methodology is considered an acceptable method of addressing accelerated thermal aging within the limitation of state-of-the-art technology. Other aging methods will be evaluated on a case-by-case basis....

The aging acceleration rate and activation energies used during qualification testing and the basis on which the rate and activation energy were established should be defined, justified, and documented.

Periodic surveillance and testing programs are acceptable to account for uncertainties regarding age-related degradation that could affect the functional capability of equipment."

Let us discuss the Arrhenius methodology as a basis for accelerated thermal aging.

The simplest form of the Arrhenius model assumes that material degradation is dominated by a single chemical process whose reaction rate is temperature dependent. The Arrhenius equation is used to relate the chemical reaction rate to temperature:

$$r = A \exp\left(-\frac{E_A}{k_B T}\right) \qquad \text{(Eq. 1)}$$

where

r = chemical reaction rate

A = pre-exponential factor (frequency)

E_A = activation energy (eV)

k_B = Boltzmann's constant

= 8.617×10^{-5} eV/°K

T = absolute temperature (°K)

Equation 1 is sometimes expressed using different units for the activation energy and the constant, k_B. You might encounter the following:

$$r = A \exp\left(-\frac{E_A}{R_T}\right) \qquad \text{(Eq. 2)}$$

where

E_A = activation energy (Kcal/mole)

R = gas constant

= 1.987×10^{-3} Kcal/mole - °K

For the remainder of this course, we will use eV units. An easy conversion factor to employ is:

$$E_A(\text{eV}) = E_A(\text{Kcal/mole})/23 \qquad \text{(Eq. 3)}$$

Equation 1 may be used to derive an expression for accelerated aging provided that mater..l degradation is dominated by a single chemical process, namely:

40 YRS

$$K = \frac{t_s}{t_a} = \exp\left\{-\frac{E_A}{k_B}\left(\frac{1}{T_a} - \frac{1}{T_s}\right)\right\} \quad \text{(Eq. 4)}$$

where

k = factor by which aging time may be reduced when the temperature is increased from T_s to T_a and still obtain same equivalent degradation

T_a = acceleration temperature (°K)

T_s = service temperature (°K)

t_s = aging time at service temperature, T_s

t_a = aging time at acceleration temperature, T_a

E_A = activation energy (eV)

k_B = Boltzmann's constant (8.617×10^{-5} eV/°K)

The pairs:

(T_s, t_s) and (T_a, t_a)

yield the same degradation when:

1. Degradation is controlled by a single process.

2. $$\frac{t_s}{t_a} = \exp\left\{-\frac{E_A}{k_B}\left(\frac{1}{T_a} - \frac{1}{T_s}\right)\right\} \quad \text{(Eq. 4)}$$

Example Two:

Problem:

A cable manufacturer produces a low voltage electrical cable using cross-linked polyethylene insulation. The cable manufacturer advertises the activation energy for thermal degradation as 1.04 eV. A nuclear power plant intends to use the cable for 40 years at a temperature of 40°C. For the qualification program, an aging temperature of 110°C will be used. How long must the cable be aged at 110°C to simulate a 40-year life at 40°C?

Solution:

$T_s = 40°C = 40 + 273 = 313°K$

$t_s = 40 \text{ years} = 14600 \text{ days}$

$T_a = 110°C = 110 + 273 = 383°K$

$t_a = ?$

$$K = \frac{t_s}{t_a} = \exp\left\{-\frac{1.04 \text{ eV}}{8.67 \times 10^{-5} \frac{\text{eV}}{°K}}\left(\frac{1}{383} - \frac{1}{313}\right)\right\} = 1150$$

$$t_a = \frac{t_s}{K} = \frac{14600 \text{ days}}{1150} = 12.7 \text{ days}$$

Example 3:

A cable manufacturer produces an electric cable with:

A copper conductor

Jacket material (40 mil thick) - E_A = 1.1 eV

Insulation material (25 mil thick) - E_A = .85 eV

A nuclear power plant intends to use the cable for the following environmental conditions:

1) 40-year exposure to service conditions

2) average service temperature = 45°C

3) maximum service temperature = 60°C

If the aging temperature is to be 130°C, for what time interval must the cable be aged?

Before we calculate the aging time, t_a, we must decide:

1. What do we use for E_A?

E_A = 0.85 eV

E_A = 1.1 eV

2. What do we use for T_s?

$T_s = 45°C$

$T_s = 60°C$

Solution to Example 3:

The cable is a composite device containing both insulation and jacketing material. Eq. 4 can be used to determine the required aging parameters for both materials, assuming:

1) a constant service temperature of 60°C

2) a constant service temperature of 45°C

The results are:

Table 7

ASSUMED CONSTANT SERVICE TEMPERATURE	JACKET (E_a = 1.1 eV)	INSULATION (E_a = .85 eV)
60°C	K = 778	K = 171
	t_a = 18.8 days	t_a = 85.4 days
45°C	K = 4740	K = 693
	t_a = 3.1 days	t_a = 21.1 days

The following conclusions may be drawn from Table 7:

1. The smaller the activation energy, the slower is the accelerated aging process. Therefore, the aging program should be based on the lower activation energy, i.e., for the insulation material.

2. The most conservative aging program would assume a constant service temperature of 60°C for the entire 40 years. Note, however, that this substantially increases aging requirements. Hence, industry should be encouraged to more precisely define environmental specifications.

The following table (Table 8) further illustrates these two conclusions:

Table 8

7 days at 121°C (394°K) is equivalent to:

Tservice	Activation Energy 1.0 eV	1.1 eV	1.2 eV	1.3 eV
90°C (363)	86.6 days	111 days	143 days	184 days
80°C (353)	214 days	301 days	424 days	1.64 yrs
70°C (343)	1.63 yrs	2.37 yrs	113 days	5.69 yrs
60°C (333)	4.23 yrs	7.25 yrs	12.44 yrs	21.33 yrs
50°C (323)	12.43 yrs	23.76 yrs	45.39 yrs	86.73 yrs

7 days at 136°C (409°K) is equivalent to:

Tservice	Activation Energy 1.0 eV	1.1 eV	1.2 eV	1.3 eV
90°C (363)	255 days	365 days	1.43 yrs	2.05 yrs
80°C (353)	1.73 yrs	2.71 yrs	4.25 yrs	6.67 yrs
70°C (343)	4.51 yrs	7.78 yrs	13.43 yrs	23.19 yrs
60°C (333)	12.45 yrs	23.79 yrs	45.46 yrs	85.88 yrs
50°C (323)	36.62 yrs	77.95 yrs	165.9 yrs	353.2 yrs

7 days at 150°C (423°K) is equivalent to:

Tservice	Activation Energy 1.0 eV	1.1 eV	1.2 eV	1.3 eV
90°C (363)	1.79 yrs	2.81 yrs	4.43 yrs	6.97 yrs
80°C (353)	4.42 yrs	7.62 yrs	13.12 yrs	22.61 yrs
70°C (343)	11.53 yrs	21.86 yrs	41.45 yrs	78.60 yrs
60°C (333)	31.84 yrs	66.84 yrs	---------	---------
50°C (323)	93.67 yrs	---------	---------	---------

Table 8
(continued)
7 days at 158°C (431°K) is equivalent to:

Tservice	Activation Energy 1.0 eV	1.1 eV	1.2 eV	1.3 eV
90°C (363)	2.97 yrs	4.92 yrs	8.16 yrs	13.50 yrs
80°C (353)	7.36 yrs	13.34 yrs	24.18 yrs	43.83 yrs
70°C (343)	19.18 yrs	38.28 yrs	76.38 yrs	---------
60°C (333)	52.99 yrs	---------	---------	---------
50°C (323)	---------	---------	---------	---------

Our solution to Example 3 was to age the composite cable at 130°C for 85.4 days. This guarantees that the cable insulation has a qualified life of 40 years. Let us consider what the qualified life for the jacket becomes:

From Table 1, we see that the minimum value of K is 778 for the jacket. Therefore

$$\text{Qualified life} \geq 778\ (85.4\ \text{days})$$

$$\geq 182\ \text{years}$$

Conceivably, the cable cannot withstand such severe aging. This may require that flexibility and engineering judgment be applied during the formulation of the qualification aging strategy.

To summarize so far:

1. It is acceptable to use the Arrhenius equation to establish accelerated thermal aging conditions.

2. Use of the lowest activation energy is most conservative.

3. Assumed values of service temperature have large impact on aging time.

   --Adding a + 15°F margin to service temperature specification may double the aging severity. (Hence, margin is not employed for aging acceleration).

   --Therefore, it is important to accurately specify service temperatures.

4. There may be a need for good engineering judgment during the development of aging strategy.

COMPLEX SYSTEMS

Now let us extend our Arrhenius aging concepts to more complex equipment items. At the simplest level, there are two common approaches.

1. List each subcomponent of the safety-related equipment. Establish for each subcomponent (usually via literature searches or manufacture contacts) an activation energy describing the thermal degradation. Choose the lowest activation energy on the list and employ it as a basis for the accelerated thermal aging program.

2. Employ an activation value such as 0.5 eV or 0.8 eV and argue that it is limiting based on "statistical" analysis for a large population of components.

Let us illustrate each of these approaches. Table 9 is an example of the first approach. It is part of an aging table for a qualification test plan. Each equipment component is listed with applicable information such as activation energies. An aging program is developed based on an anlysis of this aging table.

Westinghouse's WCAP 8587 and IEEE Std. 382-1980 (for safety-related valve actuators) are examples of the second approach. In Appendix D to WCAP 8587, Westinghouse selected an activation value of 0.5 eV for use throughout the Westinghouse program, whenever specific activation energies were not available. Their choice was based on a statistical examination of activation energies reported by EPRI for 170 materials as well as on an independent review of materials used in Westinghouse supplied equipment. The statistical distribution of activation energies for these two data bases is presented in Figures 18 and 19. Westinghouse indicates that 95% of the activation energies exceed approximately 0.4 eV from the EPRI data and 0.6 eV from the Westinghouse data. Hence they selected a valve of 0.5 eV.

The aging recommendation of IEEE Std. 382-1980 is based on an activation energy of 0.8 eV. The standard then states: "If 0.8 eV is not sufficiently conservative for the materials in the actuator being qualified, a smaller value...shall be used."

DETERMINING ACTIVATION ENERGIES

Until now we have assumed that we have access to an appropriate activation energy. Let us now discuss "determining activation energies". There obviously are two approaches-

1. You can measure the activation energy.

2. You can reference an activation energy for a similar material with a similar application.

Table 9

ARRHENIUS AGING CONCEPTS FOR COMPLEX EQUIPMENT ITEMS:

APPROACH #1: EXAMPLE

Item No.	TABLE IV. AGING MATRIX (CONTINUED) ITEM AND MANUFACTURER	MANUFACTURER'S RATING ENVIRONMENTAL AND OPERATIONAL	MATERIALS	ACTIVATION ENERGY (eV)	APPLICATION	AGING MECHANISMS TIME/ TEMPERATURE EFFECTS	AGING MECHANISMS RADIATION DAMAGE THRESHOLD	AGING MECHANISMS CYCLIC LIFE GOAL
1.6.2	Thermalloy Type 10-18	204°C Max.	Glass-Filled Diallyl Phthalate	2.17 (Ref 4)	Insulation		1×10^8 (Ref 5)	
1.7	Integrated Circuit Operating Amplifier, P/N 1153-0120-0001		Various as described below.		Electronic Component			
1.7.1	Raytheon P/N LM308	-30°C to +95°C Operating Temp.	Silicon	1.0 (Ref 6)	"	X	1×10^4 (Ref 2)	
1.7.2	National Semiconductor P/N LM308	"	"	1	"	"	"	
1.8	Transformer, Special, P/N 115 J117-0001, B. H. Electronics					"	X	
1.8.1	Wire Insulation	180°C	Polyimidamidester (Estrasol 180)	1.8 (Ref 22)	Insulation	"	Unknown	
1.8.2	Potting Shell, Durez P/N 24150	180°C U.L.	Thermosetting Alkyd	1.14 (Ref 2?)	Support	"	"	
1.8.3	Tape	150°C U.L.	Teflon	1.69 (Ref 8)	Insulation	"	1.7×10^4 (Ref 9)	
1.8.4	Potting Material, Rolph Epoxy P/N CH1069; RE2010	130°C	Epoxy	1.40 (Ref 1?)	"	"	2.5×10^9 (Ref 9)	
1.8.5	Potting Material, Castell	130°C	"	"	"	"	"	
1.8.6	Remaining Components		Metallic			NAS (Metallic)		

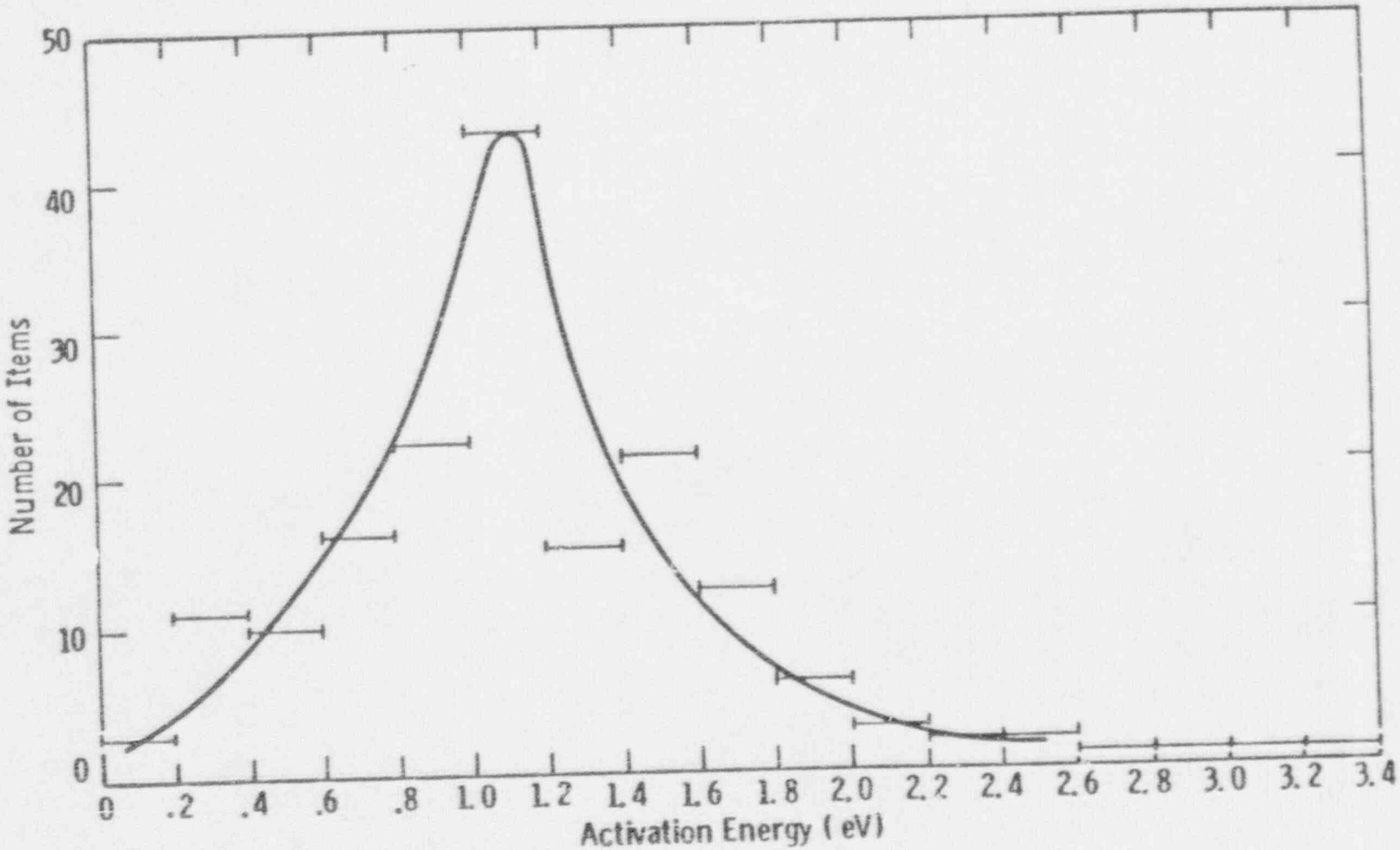


Figure D-1. Frequency Distribution of Activation Energies of Various Components/ Materials (EPRI Data)

Figure 18

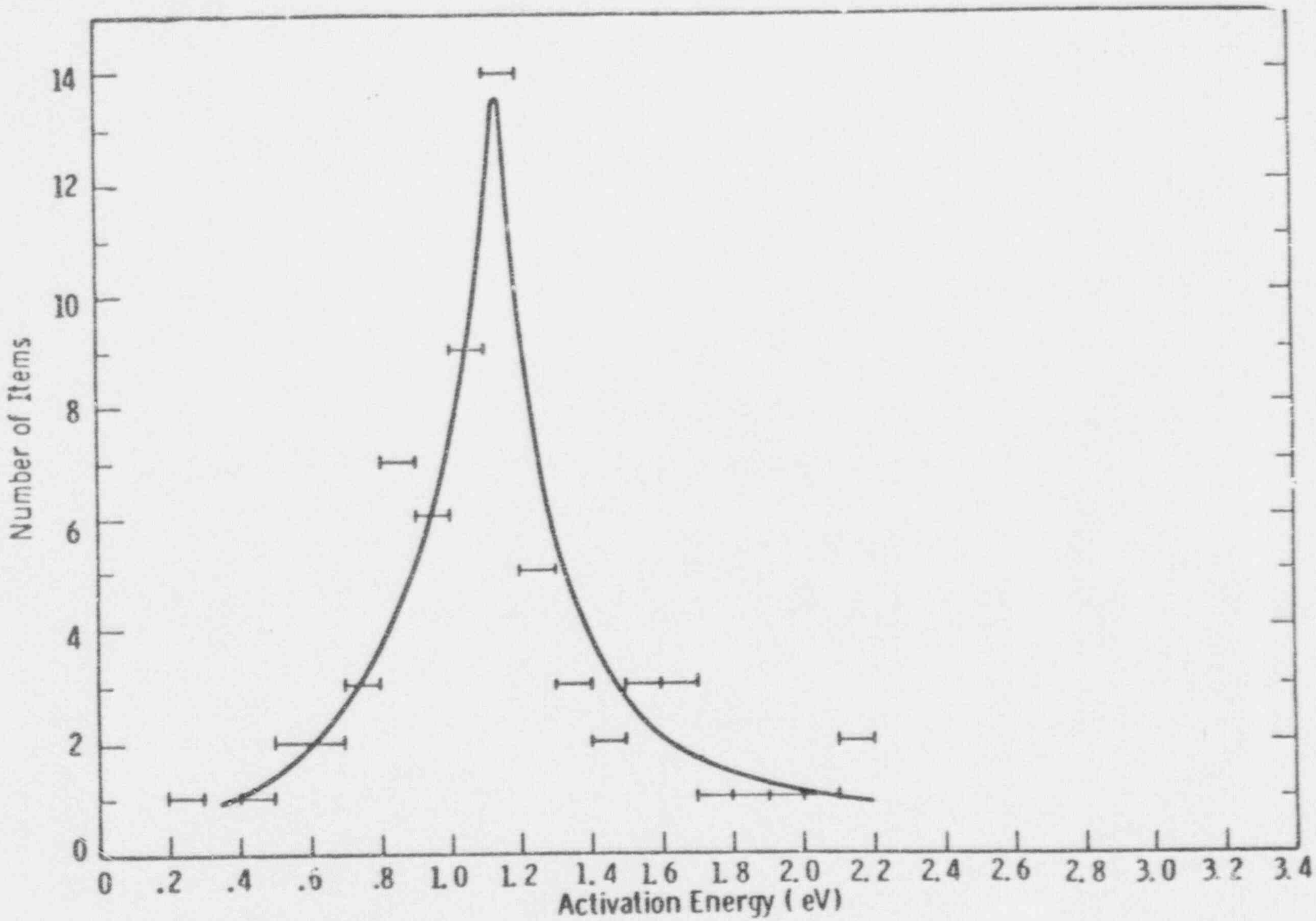


Figure D-?. Frequency Distribution of Activation Energies of Various Materials (Westinghouse Data)

Figure 19

Both approaches are commonly used and both approaches meet the Reg Guide 1.89 guidance:

> "The aging acceleration rate and activation energies used during qualification testing and the basis upon which the rate and activation energy were established should be defined, justified, and documented."

Let us first discuss how you can measure activation energies. Cable qualification efforts are good examples where activation energies are actually measured rather than referenced via a literature citation. The most important consideration is the degradation parameter to be monitored. Activation energies sometimes strongly depend on the degradation parameter. Once the degradation parameter has been chosen the following three steps will generate an activation energy.

1. Measure degradation versus time for several temperatures.

2. Choose a value of constant degradation and determine the (time, temperature) combinations that produced that level of degradation.

3. Plot (log t, 1/T) for each combination of time and temperature. The slope of the line is the activation energy divided by Boltzman's constant.

Figures 20-22 illustrate this procedure. Figures 23 and 24 illustrate some Sandia data for a Neoprene and a cross-linked polyethylene product.

Note that Neoprene (typically a jacket material) has a lower activation energy than does the cross-linked polyethylene (typically an insulation material). There is an important point that can be made with the Neoprene and cross-linked polyethylene data. The activation energy is not a measure of expected life. Rather, it is an indication of how degradation can be accelerated. For a given temperature and time exposure, Neoprene will have lost more of its tensile properties than will have cross-linked polyethylene. But cross-linked polyethylene will have more closely approached its accelerated life.

This may be of importance when "qualification by analysis" is employed to justify a manufacturing change to a product previously qualified by a type test. It is insufficient to only compare activation energies to justify similar aging tolerance. One must also compare absolute life.

A problem might develop during the measurement of activation energies. It is illustrated in Figure 25. Different temperature regimes may have different rate controlling chemical processes. Hence you could measure different activation

MEASURE DEGRADATION VERSUS TIME FOR SEVERAL TEMPERATURES

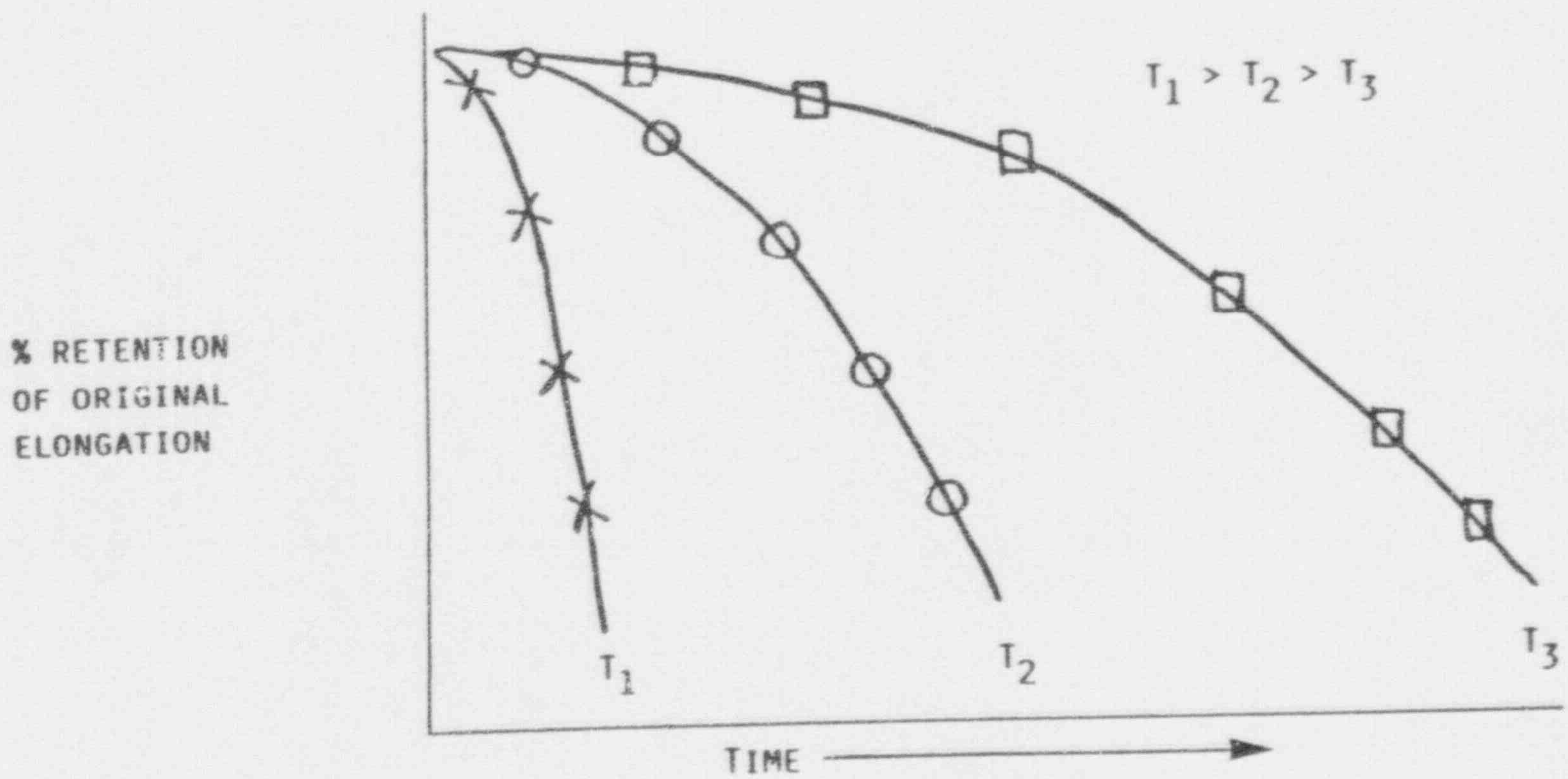


Figure 20

CHOOSE A VALUE OF CONSTANT DEGRADATION AND DETERMINE
(t_1, T_1), (t_2, T_2), ETC.

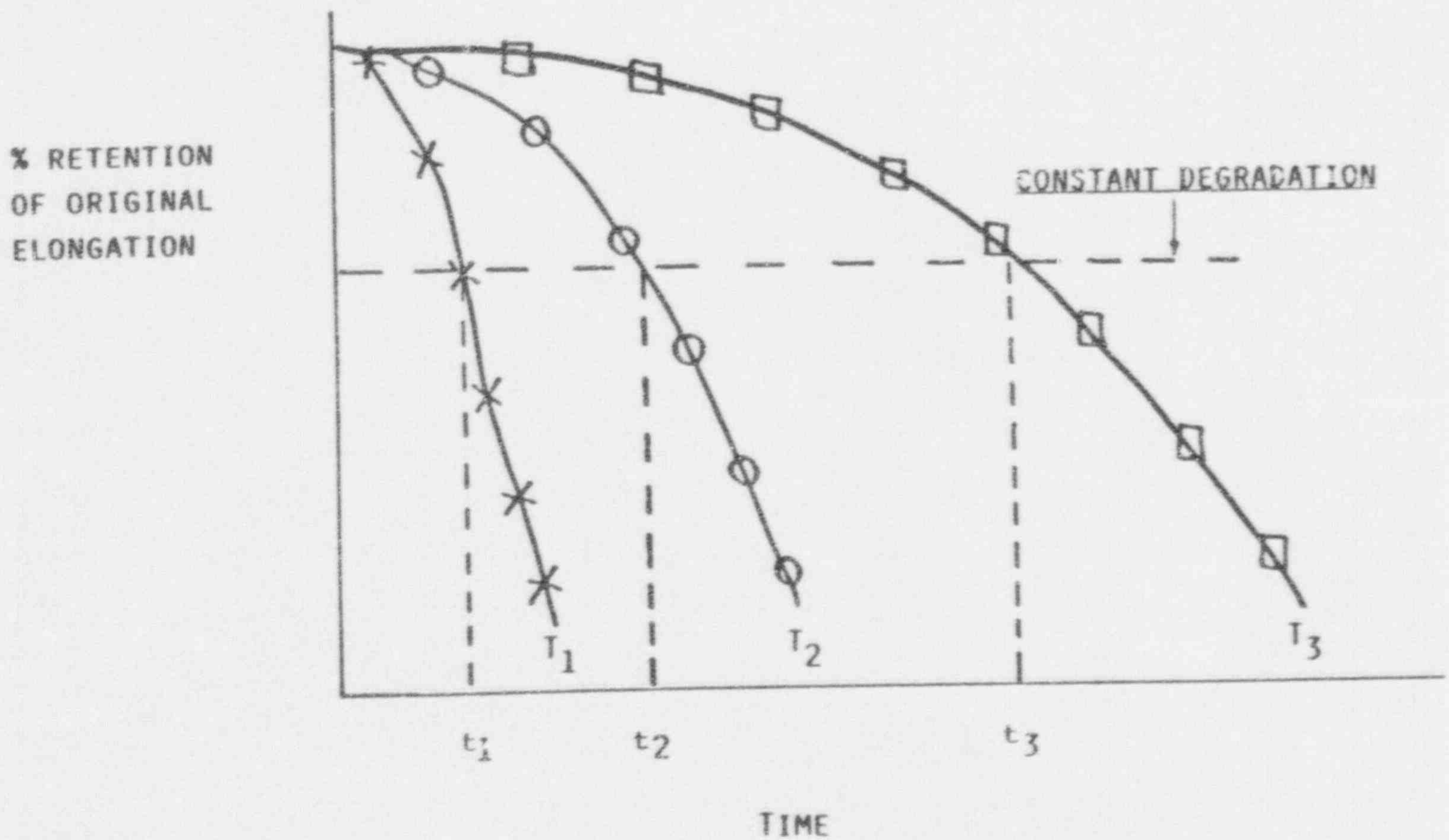


Figure 21

PLOT (LOG t_I, $1/T_I$) AND DETERMINE E_A

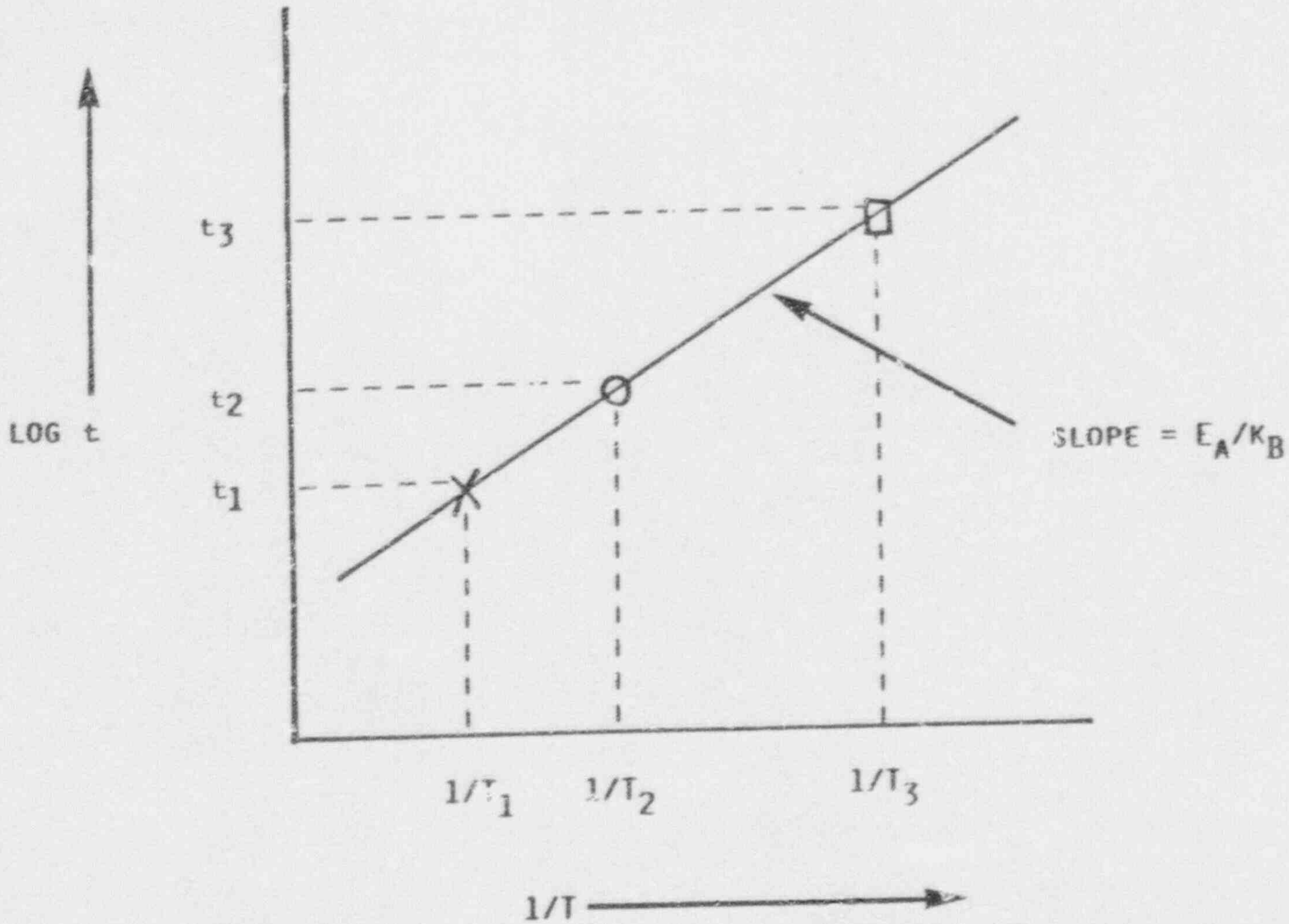
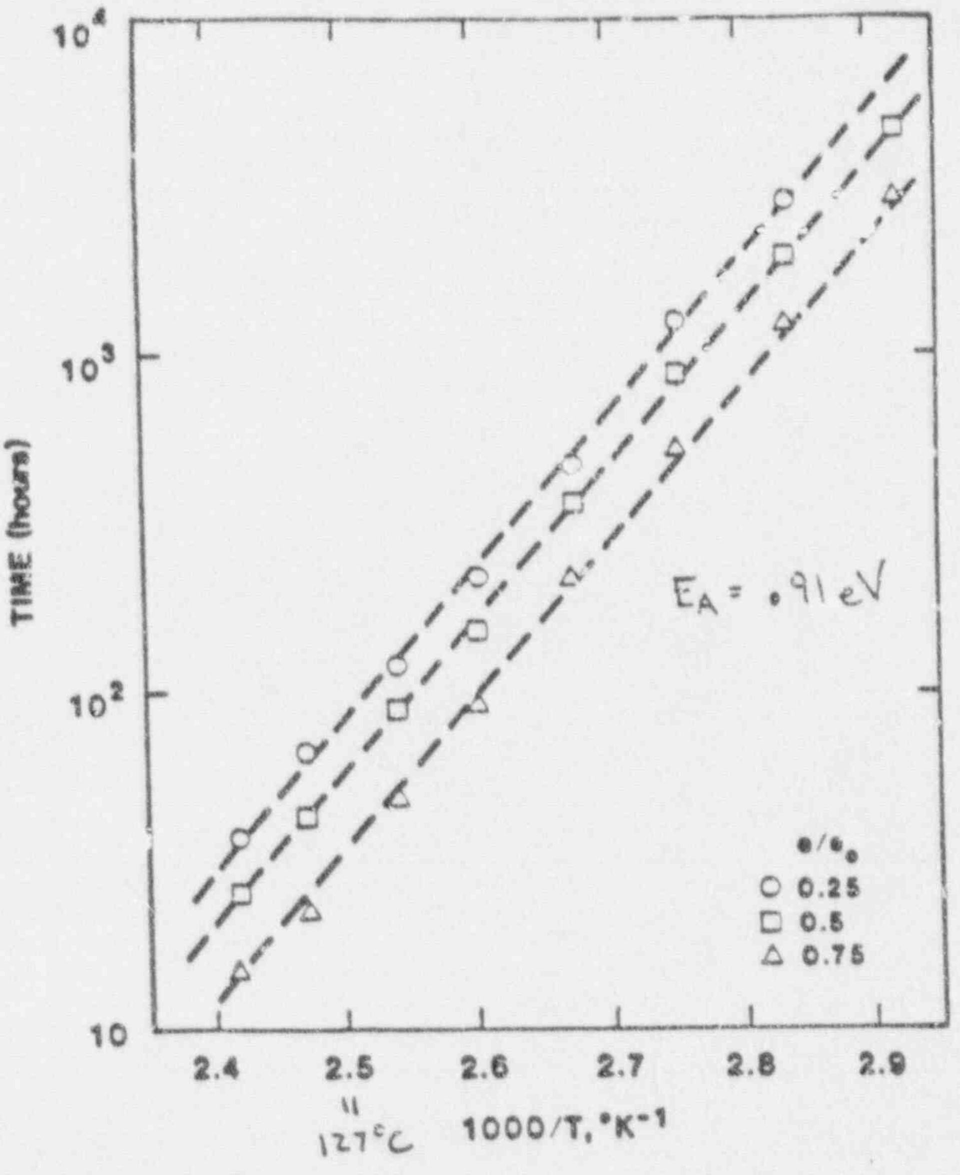
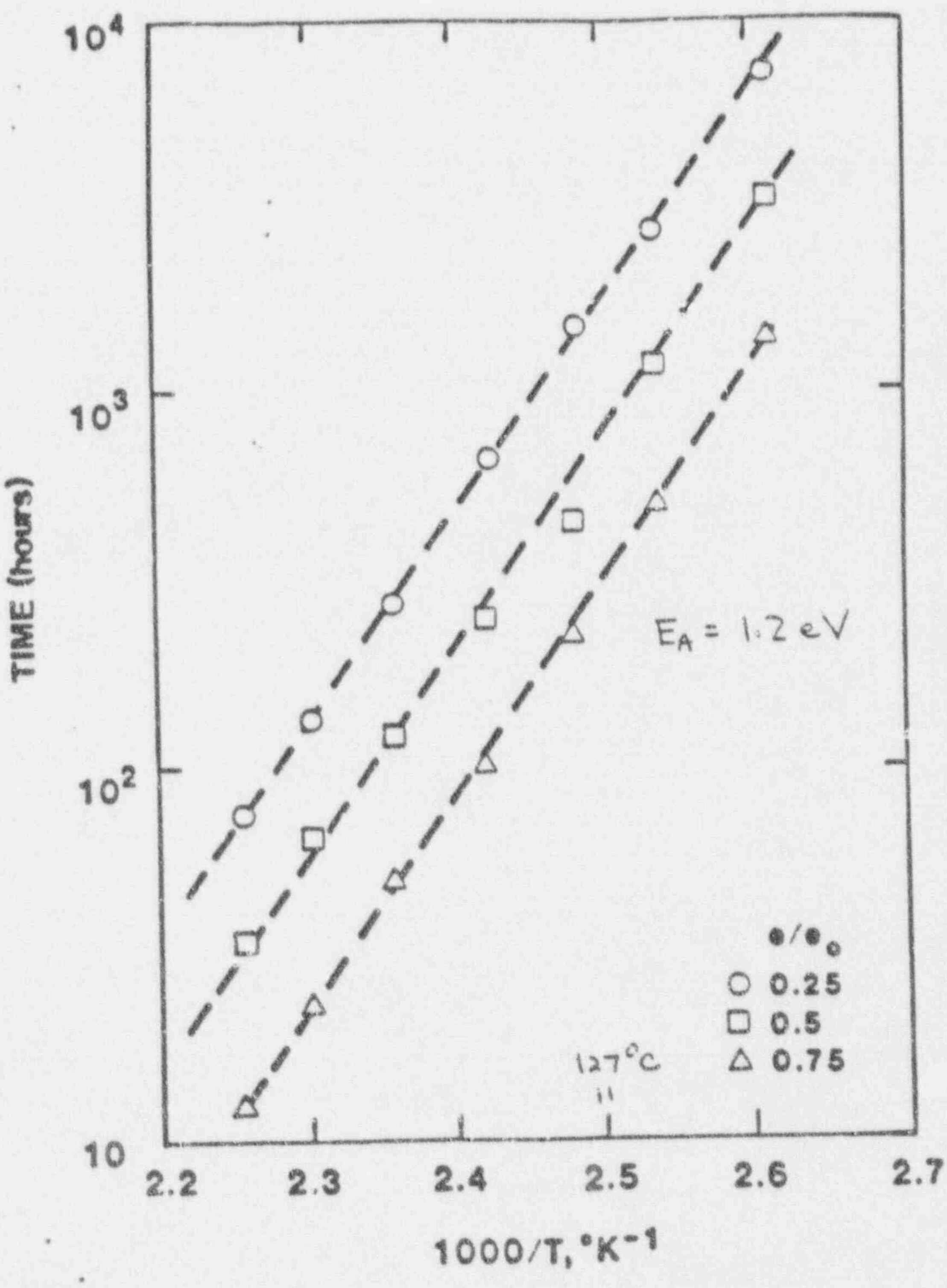


Figure 22



Arrhenius Behavior of Neoprene
(Data from K. Gillen[8])

Figure 23



Arrhenius Plot for a XLPO Cable Insulation
(Data from K. Gillen[8])

Figure 24

From:
EPRI-NP-1588

An example of an Arrhenius function which exhibits multiple breaks is shown in Figure 8-11 for a cross linked polymer material. Here, three chemical reactions are involved (1072):

AB has an activation energy of about 30 kcal, which is associated with oxygen attack on a polymer.

BC has an activation energy of about 18 kcal, which is associated with oxygen diffusion into the polymer.

CD has an activation energy of about 54 kcal, which is associated with polymer chain breaking.

At any temperature, all three reactions are simultaneously taking place. In this example, however, a particular reaction serves as the "rate controlling" mechanism for a given range in temperature.

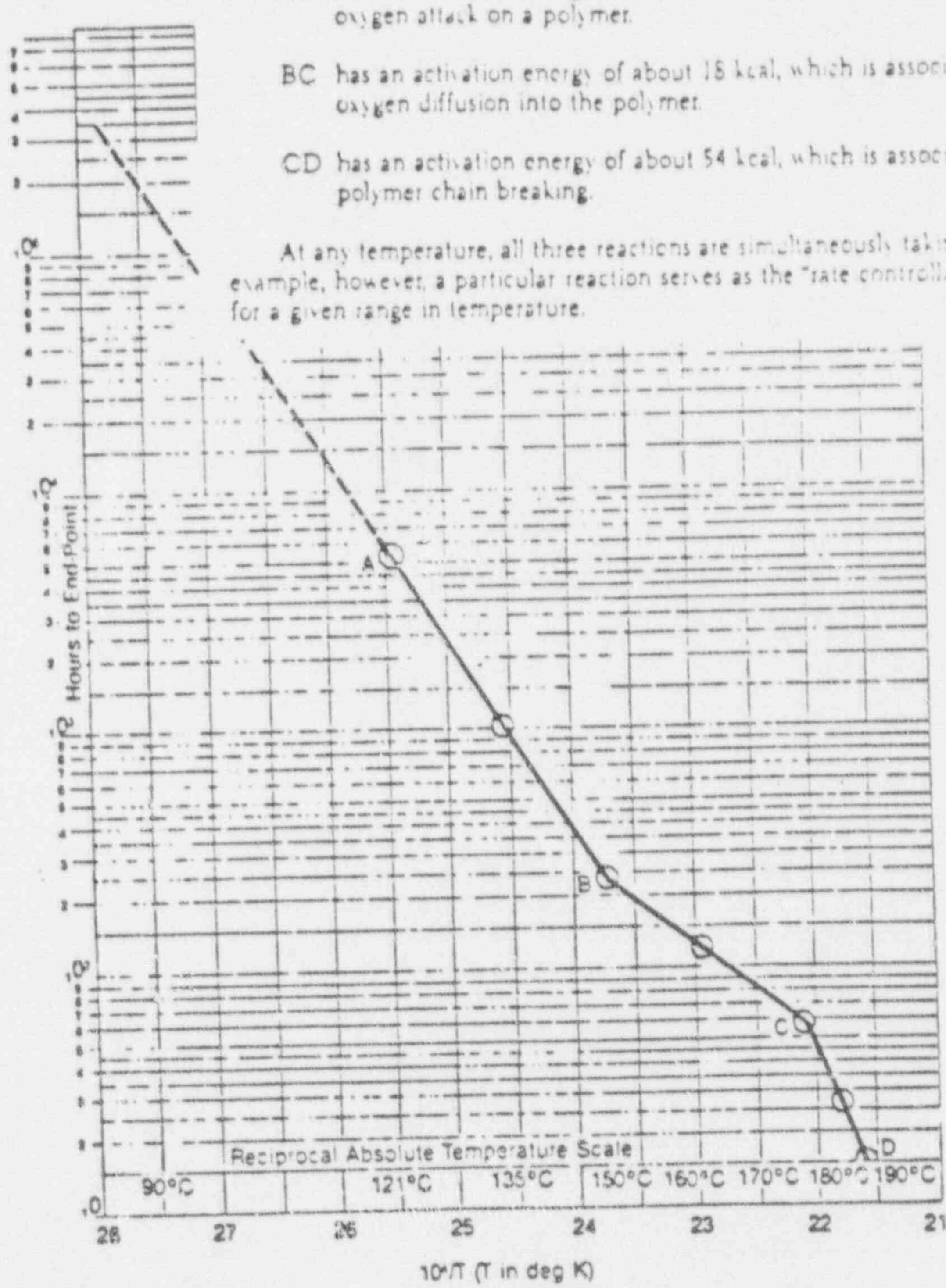


Figure 8-11.
A Typical Arrhenius Analysis of Aging

Figure 25

energies based on what temperature regime was used for the easurements. Some of the IEEE daughter standards try to account for this by recommending that certain temperatures be employed when measuring activation energies. For example, IEEE Std. 383-1974 states:

> "Aging data should be submitted to establish long-term performance of the insulation. Data may be evaluated using the Arrhenius technique. A minimum of 3 data points, including 136 C and two or more others at least 10 C apart in temperature, should be used."

Now let us examine how one establishes activation energies via a literature search. This is the most common method employed by test laboratories, especially for complex equipment. The most important considerations for a literature search are:

1. The activation energy measurement should relate to the material property of interest. For example, consider a low voltage cable. The dominant mechanism by which this cable will probably fail is mechanical degradation. Hence a tensile elongation activation energy reference would be appropriate. In contrast, a high voltage cable may fail dielectrically before it fails mechanically. Hence in this case a dielectric strength activation energy reference may be appropriate. To summarize, the inspection should assure that the degradation process monitored for the referenced activation energy is related to the postulated failure modes of the equipment.

2. It is reasonable for several different activation energies to be listed for the same generic equipment item. These variations may result from the use of different formulations or processing for the same generic material. Hence a thorough literature search may generate a list (or range) of activation energies. The lowest value on the list would generally be most appropriate.

The obvious next question is where does one find activation energies. Many test laboratories have established a proprietary library of activation energy references. There are now two public lists that are helpful. Both were generated by EPRI. The first is contained in EPRI's report EPRI NP-1588. The second is a Qualification Materials Data Bank (QMDB) that currently is being developed for EPRI.

FRom
EPRI NP-1588

Appendix B
Activation Energies

B.1 TABULATION

Activation energies for a number of materials and components are tabulated in this appendix. As in Appendix D, no effort was made to produce an exhaustive tabulation; rather, it is a convenient recording of activation energy data obtained incidentally to preparation of this report. It is essential that the cited data sources be consulted to verify the relevance to the user's application.

B.2 HISTOGRAM

A graphical representation of the distribution of activation energies, for the materials and components included in the tabulation, is given by the histogram in Figure B-1.

The values of activation energy range from 0.09 eV for titanium titanium dioxide, thin-film capacitors to 3.29 eV for Kraft paper. This range was divided into 0.2-eV increments, and the number of materials and components that have an activation energy within a given increment was counted (from the tabulation). These numbers were then used to plot the histogram. The large number of entries for magnet wire contributes substantially to the histogram over a broad range from 0.2 to 1.8 eV, except in the interval between 1.2 and 1.4 eV. Polymers and transistors make a major contribution to the peak between 1.0 and 1.2 eV.

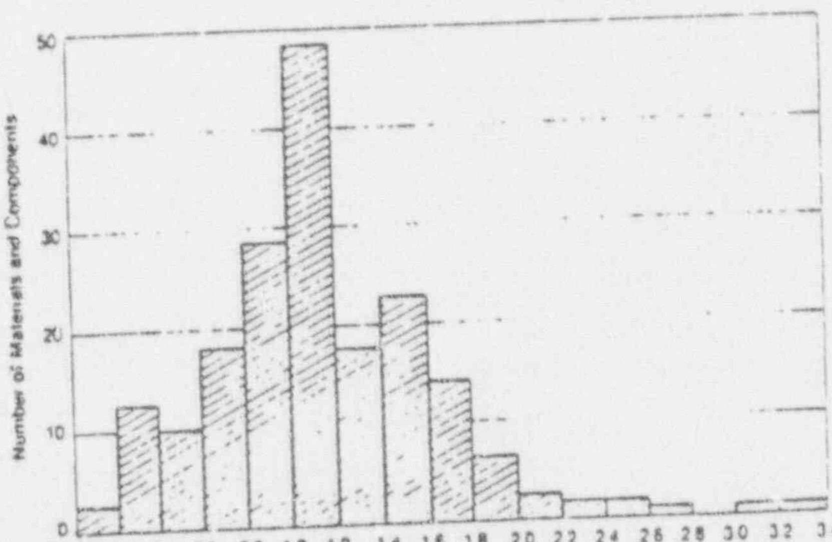


Figure B-1.
Histogram of Activation Energies

FROM: EPRI NP-1588

NOTES FOR TABULATED ACTIVATION ENERGIES

Notes:

1. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). No impregnate.
2. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). Impregnated.
3. Encapsulated with B staged aromatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy transfer molded). No impregnate.
4. Encapsulated with B staged aromatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy transfer molded). Impregnated.
5. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot melt). No impregnate.
6. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot cast). Impregnated.
7. Encapsulated with modified anhydride cured bisphenol A-epichlorhydrin epoxide. No impregnate.
8. Encapsulated with mixed anhydride cured epoxy novolac. No impregnate.
9. Failure criteria: cracking of insulation to expose conductor, dielectric breakdown, leakage current > 300 μA at 3000 V. All specimens tested to failure.
10. Failure criterion: voltage stress of [illegible] volts held for 15 seconds at 100% R.H. All specimens tested to failure.
11. Based on graph of log mean time to failure vs. 1/T.
12. Failure criterion: 3 A drawn at rated voltage. All samples tested to failure.
13. Post-cured @ 125°C, then [illegible] life testing @ [illegible]°C. Main failure mode was high leakage currents.
14. Calculated from Arrhenius type plots.

Material/ Component Device	Activation Energy (eV)	Citation	Remarks
Alkyd, Grade 1500	1.71	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Alkyd, Grade 1500	1.14	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Alken-imide, irradiated, insulation, 20 gauge wire	0.88	461	MIL-W-81044/17A. Mean time to failure. Notes 9 and 14.
Aromatic polyimide, insulation, 20 gauge wire	1.29	461	MIL-W-81381/12. Mean time to failure. Notes 9 and 14.
Butyl	1.08	603	40% loss of elongation. See Note 14.
Capacitors, chlorinated diphenyl. No stabilizers.	1.17	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl. 0.5% anthraquinone	1.53	566	DC life. Stressed at 1000 volts per mil. See Note 14.

FROM: EPRI - NP - 1558

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Capacitors, chlorinated diphenyl. 0.5% azobenzene	2.00	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper	0.56	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 0.5% azobenzene	1.50	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 5.0% azobenzene	1.93	150	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitor, dielectric, tubular paper	2.42	717	10% capacitance increase. See Note 14.
Capacitors, metalized paper	1.32	150	Life defined as time required to regain original value of capacitance after initial increase. See Note 14.
Capacitors, titanium-titanium dioxide, thin-film @ 25°C-100°C	0.09	466	Formed by anodization. Tests with rate of temperature rise approximately 2½°C/min.
Choseal (Chomeric Inc.) (Silver filled conductive silicone)	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Connectors: Thin gold (25-100μ) electroplated over copper base material			$D = D_o \exp(\varepsilon/kT)$, where D = chemical interdiffusion coefficient and $D_o \cong 1.5 \times 10^{5}$ cm²/s.
(250°C - 750°C)	1.02	433	Predominant degradation mechanism is defect diffusion along grain boundaries and dislocation pipes—dependent upon defect density.
(50°C - 250°C)	0.50	433	
Dacron, Parachute material (polyethylene glycol terephthalate, see see Ref. 124)	1.15	765	Determined by thermogravimetric analysis. Heating rate of 2°C per minute
Diallyphthalate, glass filled	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Diodes, Si			
–general	1.13-2.77	540	
Diodes, Si (–1960)	1.14	540	

FROM: EPRI-NP-1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Diode, silicon, 1N673 and 1N696	1.50	339	50% failure. See Note 14.
Diodes, silicon, p-n-p-n	1.41	340	
Diodes, silicon, varactors	2.31-2.38	340	
Diodes, others	1.13-2.77	340	
Diodes, varactors	2.31-2.38	340	
Ethylene propylene, No. 8 lead wire with paper separator	0.71	374	See Note 14.
Ethylene propylene	1.28	51	20% loss in elongation. See Note 14.
Ethylene propylene base insulation	1.05	603	40% loss of elongation. See Note 14.
Ethylene propylene, No. 18 lead wire	0.90	374	Estimated average life. See Note 14.
Ethylene propylene, solid — with paper separator	0.70	374	10,000 h life @ 11[illegible]°C
Ethylene propylene, solid	0.95	374	10,000 h life @ 152°C
Enamel, plain, insulation on magnet wire	0.55	610	See Notes 3, 11 and 14.
Enamel, plain, insulation on magnet wire	0.64	610	See Notes 2, 11 and 14.
Enamel, plain, insulation on magnet wire	1.61	610	See Notes 1, 11 and 14.
Enamel, plain, insulation on magnet wire	0.38	610	See Notes 4, 11 and 14.
Enamel, plain, insulation on magnet wire	0.45	610	See Notes 5, 11 and 14.
Enamel, plain, insulation on magnet wire	0.28	610	See Notes 6, 11 and 14.
Epon 828 (Shell Chemical)	1.34	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Epoxy (epoxide film), insulation, magnet wire	0.71	368	See Note 14.
Epoxy, Grade 2000	0.98	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.

FROM: EPRI-NP-1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Epoxy, Grade 2000	1.24	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Epoxy insulation on magnet wire	0.99	610	See Notes 1 and 11.
Epoxy insulation on magnet wire	0.94	610	See Notes 2 and 11.
Epoxy insulation on magnet wire	0.87	610	See Notes 3 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 4 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 5 and 11.
Epoxy insulation on magnet wire	0.93	610	See Notes 6 and 11.
Epoxy, unvarnished, magnet wire	0.67	832	See Note 14.
Epoxy, phenolic varnished, magnet wire	0.66	832	See Note 14.
Formvar (Bondege), cementable insulation and Andover Corp. epoxy encapsulant	1.09	320	See Note 14.
Formvar, cementable insulation and epoxy encapsulant – solenoid coil	0.70	320	See Note 14.
Formvar insulation on magnet wire	1.61	610	See Notes 1 and 11.
Formvar insulation on magnet wire	0.23	610	See Notes 3 and 11.
Glass, high lead	0.37	97	
Isonel – 175 insulation and Acme 2008 epoxy encapsulant on solenoid coil.	0.68	320	Average coil life. See Notes 12 and 14.
Kraft paper in mineral oil.	1.39	838	50% of tensile strength. See Note 14.
Kynar. MIL-specification wires	1.95	374	See Note 14.

FROM: EPRI-NP-1558

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Microcircuits, CMOS type CD 4024A	1.0	795	25h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS type CD 4013A	1.1	795	42h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS, type CD 4011A	1.4	795	90h @ 250°C = 50% failure. See Note 13.
Microcircuit, CMOS 4007 freak pop.	0.9	517	
main pop.	1.3	517	
ML #18 twist pairs	1.43	610	See Notes 7 and 11.
ML #33 coils	1.15	610	See Note 8. Failure criteria was shorted turn, open circuit and/or 2500 volt hipot failure of coil.
ML #18 twist pairs	2.44	610	See Note 8.
Mylar film	1.18	559	Data based on 50% electric strength failure. See Note 14.
Neoprene	0.87	401	70°C - 130°C.
Nitrile	0.86	401	70°C – 100°C.
Nyleze insulation on magnet wire	0.57	610	See Notes 6 and 11.
Nyleze insulation on magnet wire	0.99	610	See Notes 1, 11 and 14.
Nyleze insulation on magnet wire	0.75	610	See Notes 2, 11 and 14.
Nyleze insulation on magnet wire	0.68	610	See Notes 3, 11 and 14.
Nyleze insulation on magnet wire	0.59	610	See Notes 4, 11 and 14.
Nyleze insulation on magnet wire	1.04	610	See Notes 5, 11 and 14.
Nylon 6/6, glass-reinforced	1.14	530	Tested at 205 and 255°C. 50% reduction in tensile strength. See Note 14.
Nylon 6/6, glass-reinforced	1.29	530	Tested at 140 and 150°C. 50% reduction in tensile strength. See Note 14.

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Operational Amplifier 741			
– freak pop.	0.7	517	
– main pop.	1.6	517	
– mixed pop.	0.8	517	
– freak pop.	0.8	517	
– main pop. (½ voltage)	0.9	517	
Paper, manila, under oil	1.66	566	Reduction of tensile strength to 20% of original strength. See Note 14.
Paper, manila, under oil	1.56	566	Reduction of tensile strength to 70% original strength. See Note 14.
Penolic, general purpose, Durez 791	1.36	1026	50% retention of impact strength (Hooker Corp.). See Note 14.
Phenolic, general purpose, Durez 791	1.05	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	0.96	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	1.11	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.16	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.43	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade [illegible]35	1.27	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic Kraft laminate	1.47	573	75% retention of flexural strength. See Note 14.
Phenolic Kraft laminate	1.50	573	50% retention of flexural strength. See Note 14.
Polyester, amide-imide overcoated, helical coil	1.54	943	See Note 14.

From: EPRI-NP-1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyester, amide imide overcoated, wire, twisted pairs	1.25	943	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating varnish	1.26	832	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating varnish, in motorette systems	1.66	832	See Note 14.
Polyester-overcoated, unvarnished twists of magnet wire.	1.44	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.67	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.56	832	See Note 14.
Polyester, phenolic varnished, magnet wire.	1.04	832	See Note 14.
Polyester resins (unjelled) Hetron 24305, 853, 354 and Maro 670.	0.87	356	
Polyester, unvarnished, magnet wire.	1.00	832	See Note 14.
Polyethylene, cross-linked	1.13	603	40% loss of elongation. See Note 14.
Polyethelene, cross-linked	1.25	51	20% loss in elongation. See Note 14.
Polyethylene, 0.92 density	1.15	973	t_{10} induction periods. See Note 14.
Polyethylene, low density (below 97°C)	1.51	973	Extrapolated induction periods. See Note 14.
Polyethylene, 0.96 density	1.14	973	t_{10} induction periods. See Note 14.
Polyethylene, low density	1.35	973	(Above 110°C) extrapolated induction periods. See Note 14.
Polyethylene, linear	3.10	537	10% weight loss in vacuum. See Note 14.

From: EPRI-NP-1588

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polypropylene, isotactic	1.13	973	t_{10} induction periods. See Note 14.
Polyalkene – polyvinylidene fluoride, irradiated, insulation, 20 gauge wire.	1.10	461	MIL-W-81044/9. Mean time to failure. See Notes 9 and 14
Printed circuit board material ($^1/_{32}$ in.), NEMA G-10 and FR-4	1.05	717	50% retention of electrical strength. See Note 14.
Printed circuit board material ($^1/_{32}$ in.) NEMA G-10 and FR-4	1.49	717	50% retention of flexural strength. See Note 14.
Polyimide, aromatic, TFE banded and coated insulation, 20 gauge wire.	1.57	461	Meantime to failure. See Notes 9 and 14.
Polymethylmethacrylate	0.34	890	
Polytetrafluoroethelene	0.43	890	
Polytetrafluoroethylene	3.29	557	10% weight loss in vacuum. See Note 14.
Polythermaleze, heavy, insulation and 3M 241 epoxy encapsulant on solenoid coil.	0.95	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation and Acme 4027-A epoxy encapsulant on solenoid coil.	0.92	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 1 and 11.
Polythermaleze insulation on magnet wire.	0.96	610	See Notes 2 and 11.
Polythermaleze insulation on magnet wire.	1.56	610	See Notes 3 and 11.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 4 and 11.
Polythermaleze insulation on magnet wire.	0.98	610	See Notes 5 and 11.
Polythermaleze insulation on magnet wire.	0.75	610	See Notes 6 and 11.

From: EPRI-NP-1558

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polythermaleze #33 on coils.	0.87	610	See Note 7. Failure criteria was shorted turn, open circuit and/or 2500 volt hipot failure of coil.
Polystyrene	0.26	890	
Polyurethane insulation on magnet wire.	0.49	610	See Notes 6 and 11.
Polyurethane insulation on magnet wire.	0.29	610	See Notes 4 and 11.
Polyurethane insulation on magnet wire.	0.32	610	See Notes 5 and 11.
Polyurethane insulation on magnet wire.	0.38	610	See Notes 2 and 11.
Polyurethane insulation on magnet wire.	0.25	610	See Notes 3 and 11.
Polyurethane insulation on magnet wire.	0.46	610	See Notes 1 and 11.
Polyvinylacetate	0.16	890	
Polyvinylchloride	0.26	890	
Polyvinyl formal, magnet wire twists, with phenolic alkyd varnish.	0.80	832	See Note 14.
Polyvinyl formal, magnet wire, with phenolic type varnish.	0.62	832	See Note 14.
Polyvinyl formal, with phenolic type varnish, magnet wire.	0.93	832	See Note 14.
Polyvinyl formal, with phenolic type impregnating varnish, magnet wire.	1.04	832	See Note 14.
Polyvinyl formal, unvarnished, magnet wire.	1.01	832	See Note 14.
Polyvinyl formal enamel and oil modified phenolic varnish, magnet wire.	0.98	368	See Note 14.
Polyvinyl formal, unphenolic type varnish, magnet wire.	0.84	832	See Note 14.

From: EPRI - NP - 1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyvinyl formal, impregnated with phenolic type varnish, magnet wire.	1.03	832	See Note 14.
PVC-nylon insulation, 20 gauge wire	1.40	461	MIL-W-5086/2. See Notes 9 and 14.
PVC, irradiated, insulation, 20 gauge wire.	0.99	461	See Notes 9 and 14.
Resin-mica insulation, solventless	0.70	179	Loss factor in stator coils during 10-year field service increased in accordance with Arrhenius model to a peak.
Semiconductor devices, silicon.	0.9-1.4	86	Predominant value ~ 1.1 eV.
Silicon 6-110-6 (Dow Corning)	1.14	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Silicone, modified, wire enamel on copper without varnish.	1.56	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on copper with silicone varnish.	1.61	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on aluminum without varnish.	1.46	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicon transistors and integrated circuits	1.1	184	Testing of transistors and integrated circuits based on Arrhenius model.
SML insulation and Jones-Dabney epoxy encapsulant.	0.72	320	See Note 14.
Termination, tinned round wire (Sn, Sn + SnPb, Au, Ag)	0.77	69	Present aging relation: 16 h @ 155°C = 5 yr @ room temp. Recommended relation: 4 h @ 155°C = 5 yr @ room temp. Failure caused by: high temperature, high humidity, sulfur-dioxide.

From: EPRI-NP-1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Thermaleze "B" (epoxy polyester film), insulation magnet wire.	1.0	368	See Note 14.
Thermaleze-F insulation and Jones-Dabney epoxy encapsulant.	1.10	320	See Note 14.
Thermalon insulation and 3M 241 epoxy encapsulate on solenoid coil.	0.42	320	Average coil life. See Notes 12 and 14.
Transistors	0.66	123	
Transistor, Ge alloyed, OC 1972 (1964)	1.26	235	
(1966)	1.08	235	
Transistor, Ge alloy LT123 (1958).	1.25	670	
Transistor, bipolar, p-n-p-n	1.65	340	
Transistors, CMOS	1.16	334	Eyring model.
Transistor, diffused-geronium	0.[illegible]7	340	Step-stress tests without moisture getter. Median life. See Note 14.
Transistor, diffused-germanium	1.24	340	Constant stress tests with moisture getter. Median life. See Note 14.
Transistor, Ge gettered	1.24	340	
Transistor, Ge mesa, AF106 (1969)	1.00	235	
Transistor, Ge mesa, 2N559 (1958)	1.17	671	
(1959)	0.95	671	
(1960)	1.14	671	
Transistor, Ge MADT, 2N501 (1958)	1.07	673	MADT = Micro alloy diffused transistor
Ge MADT, 2N501 (1959)	1.[illegible]7	674	
Transistor, Ge MAT, 2N393 (1960)	1.0	673	MAT = Micro alloy transistor
Transistor, Ge MAT, 2N393 (1959)	1.00	673	MAT = Micro alloy transistor
Transistor, Ge ungettered	0.88	340	

From: EPRI-NP-1558

Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Transistors, germanium @ 60°C.	0.99-1.26	136 (Appendix)	
Transistors, germanium	0.17	236	Near and below room temperature
Transistor, germanium, ungettered	0.88	340	
Transistors, germanium, gettered with vycor or molecular sieve	1.24	340	
Transistor, Si mesa, 2N269 (1961)	0.38 0.58	677 677	Conditions not specified. Constant stress.
Transistor, Si mesa, 2N560 (1959) (1960)	1.12 1.50	672 672	
Transistor, Si mesa, 2N1051 (1960)	1.12	671	
Transistor, modern submarine cable	1.4	129	
Transistors, MOS	1.2	129	
Transistors, MOS	1.10	157	Median life for failure criterion of 1.0-V shift. See Note 14.
Transistors, MOS	1.10	157	Median life for failure criterion of 0.5-V shift. See Note 14.
Transistor, power, MSC 1330	0.81	125	Median time to failure. See Note 14.
Transistors, Si main pop. (1960)	1.02	340	
Transistor, Si planar, BFY 33 (1969)	1.12	235	
Transistor, Si planar, 4A-2(1967) (1967) (1963)	1.18 1.50 1.29	675 675 676	Step stress. Constant stress. Constant stress.
Transistor, Si, p-n-p-n	1.65	340	
Transistors, silicon, (All) – before wearout – at wearout	 1.12 1.46	 235 235	
Transistor, silicon, bipolar	1.02	340	With surface inversion failures.
Transistor, silicon, bipolar	1.02-1.04	340	With Au-Al bond failures.

From: EPRI - NP-1558

Activation Energies

Material/ Component Device	Activation Energy (eV)	Citation	Remarks
Transistor, silicon, bipolar	1.77	340	With metal penetration into Si.
Transistor, silicone mesa, 2N560	2.16	339	50% failure. See Note 14.
Transistors, silicon, typical	0.96	340	t_{10} lifeline. See Note 14.
Transistors, silicon, typical	1.11	340	t_{50} lifeline. See Note 14.
Transistors, submarine-cable	1.30	157	0.025% failure. See Note 14.
Transistors, submarine cable	1.24	129	50% failure. See Note 14.
Transistors, 2N559, vacuum baked.	0.59	750	Median life based on failure criteria of collector breakdown voltage and reverse current, and emitter breakdown voltage. See Note 14.
Transistor, Vycor gettered germanium, 2N559.	1.02	339	50% failure. See Note 14.
Viton A (DuPont)	1.11	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Wire, aircraft, Type I, Size 14	1.66	360	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type II, Size 8	1.77	365	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type II, Size 14.	1.56	365	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 14.	1.57	368	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 8.	1.96	365	MIL-W-5086A. Average life. See Notes 10 and 14.

INSPECTION QUESTIONS

Let us summarize some questions that could help focus a thermal aging inspection.

Request a parts list and drawing for the device. Check that all non-metallic components of the device are identified in the aging analysis. For those components deemed necessary for safety-related function, make sure they were considered in the aging analysis. Were self-heating effects accounted for in the aging analysis? Check the maximum rated temperature for each component and insure that the aging temperature employed during accelerated aging is not higher than this temperature. Check the normal operating temperature given for the device. Is it consistent with process fluids or other environments in contact with the device.

Check a few random activation energy references. Is the degradation mechanism for the component similar to that measured for the activation energy analysis? Does supporting data indicate that the measured activation energy is independent of temperature or was there a strong temperature dependence? If a temperature dependence occurred, were the high or low temperature regimes used to determine the activation energy? When literature references are employed as a basis for estimating generic activation energies, is a list of literature references supplied? From the range of possible values was the lowest value chosen as a basis for qualification? Does a test laboratory or manufacturer consistently employ the same literature reference for the same generic material? When analysis is employed to argue component similarity (and hence qualification by similarity) did the analysis consider component lifetime as well as component activation energy?

Verify the aging calculation by checking the mathematics. Make sure that the intended qualified life is clearly stated and is consistent with stated maintenance requirements.

SOME ADDITIONAL THOUGHTS ON THERMAL AGING

So far we have discussed thermal aging using an equation. Many people prefer a graphical approach to develop thermal aging requirements. Both approaches are "theoretically" identical. Let us first review the equation approach and then relate it to the graphical approach.

In the equation approach you first generate thermal aging data. This data is plotted on a log(t) versus 1/T plot which yields a ight line with slope related to the activation energy. Once you calculate the activation energy from the slope, you employ it in the Arrhenius equation to determine aging conditions.

An alternative approach is to generate the log(t) versus 1/T plot. Then choose your aging goal (say 40 years at 90 C) and identify that point on the plot. Draw through that point a straight line parallel to your original data (i.e., with the same slope and hence with the same activation energy). Any combination of (log(t), 1/T) on the newly constructed line is equivalent to your desired aging condition. For example, suppose the line passes through the point (log(2 weeks), 1/423K). Then a two week exposure at 423 K (150 C) would be equivalent to the 40 year exposure at 90 C. This approach to thermal aging analysis is demonstrated in Figure 26.

One final topic deserves mention before we leave the issue of thermal aging. The topic concerns whether thermal aging may enhance equipment performance and thus mask a potential common mode failure. Let us review again the 10 CFR 50.49 aging requirement. 10 CFR 50.49 states that:

> "Equipment qualified by test must be preconditioned by natural or artifical (accelerated) aging to its end-of-installed life conditon."

Note that this requirement is worded slightly (but importantly) different than the requirement specified in IEEE Std. 323-1974. Section 6.3.2(4) of IEEE Std. 323-1974 states:

> "Equipment shall be aged...to put it in a condition which simulates its expected end-of-qualified-life condition."

The difference is best expressed by considering the IEEE daughter standard 381-1977 for Class 1E Modules. In Section 5.8 this standard states:

> "In some instances, aging may actually improve equipment capability to perform.... In such cases it is, therefore, recognized that to demonstrate the capability of some Class 1E modules to perform their saf y-related function may require that they be subjected to design basis event conditions with minimum or no aging (that is, new or partially aged modules may, in some cases, be limiting."

AN AGING PROGRAM CAN BE DETERMINED WITHOUT EVALUATING THE ACTIVATION ENERGY

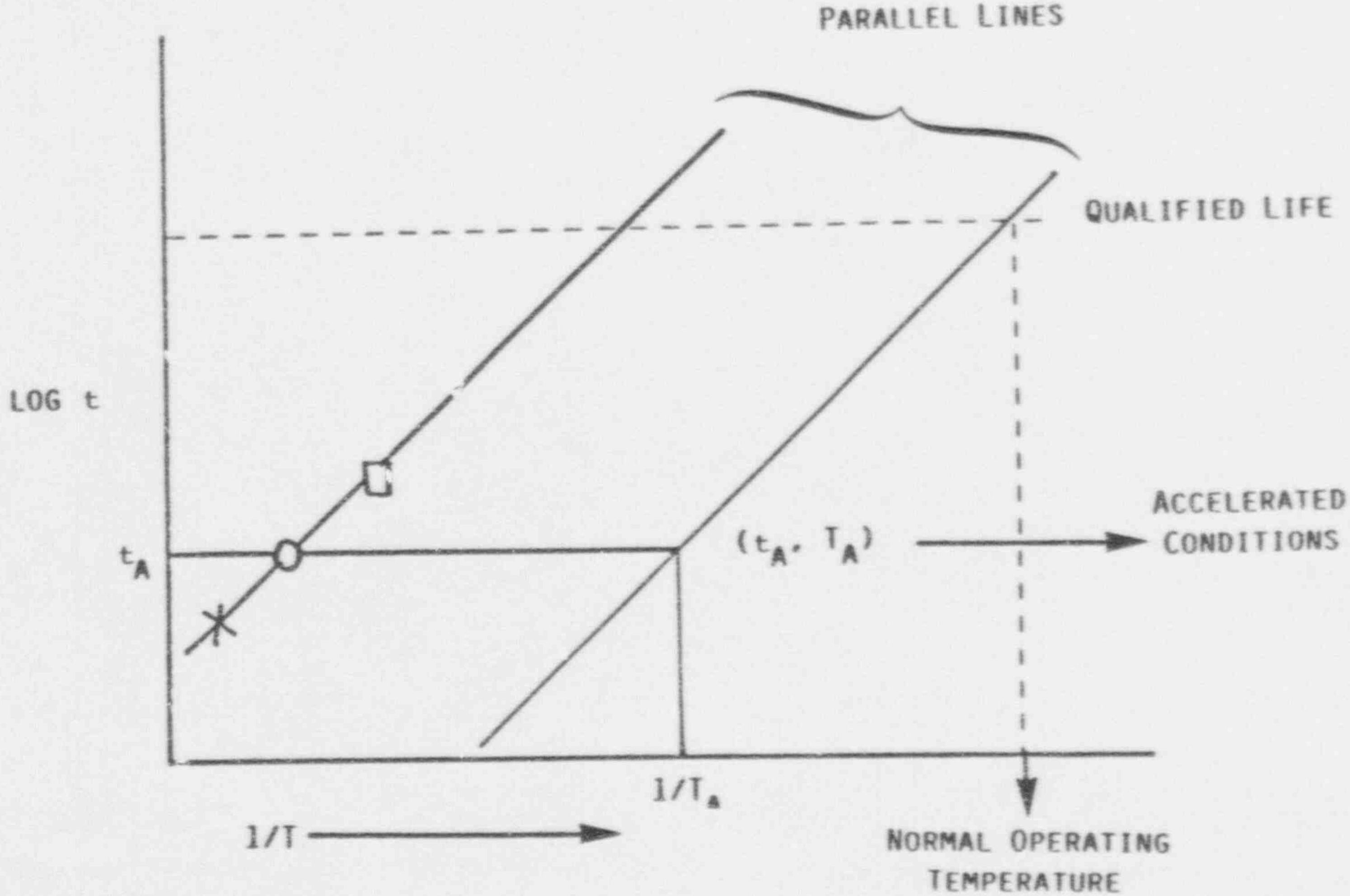


Figure 26

EXAMPLE 2

IE Information Notice 83-72 mentions a thermal non-repeatability in the performance of ITT Barton's transmitter, models M-763 and M-764. A leakage current path through the shafts of the zero and span potentiometers was detected by Barton. Of interest is why this performance was not noted during qualification testing.

Testing at Sandia of these transmitters suggested that the leakage current was enhanced by moisture driven from the nylon in the potentiometer. This moisture had a transient phenomena. During the temperature transient, moisture was driven out of the nylon producing a leakage path along the shaft of the potentiometer. As the temperature exposure continued, the moisture dryed and the leakage reduced.

Figure 27 illustrates a LOCA temperature profile employed at Sandia to test Barton transmitters. Figure 28 illustrates the corresponding transmitter error. Note that as the LOCA proceeds the error reduces. One can postulate that if the LOCA exposure had been proceeded by a thermal aging environment, then all moisture would have been driven away from the nylon in the potentiometer and no error would have been noted during the qualification test. The message is that age preconditioning, while important, may not produce the most limiting condition for Class 1E equipment.

Figure T5-A-5

Trans. T5 First 26 hrs. Temp. Profile

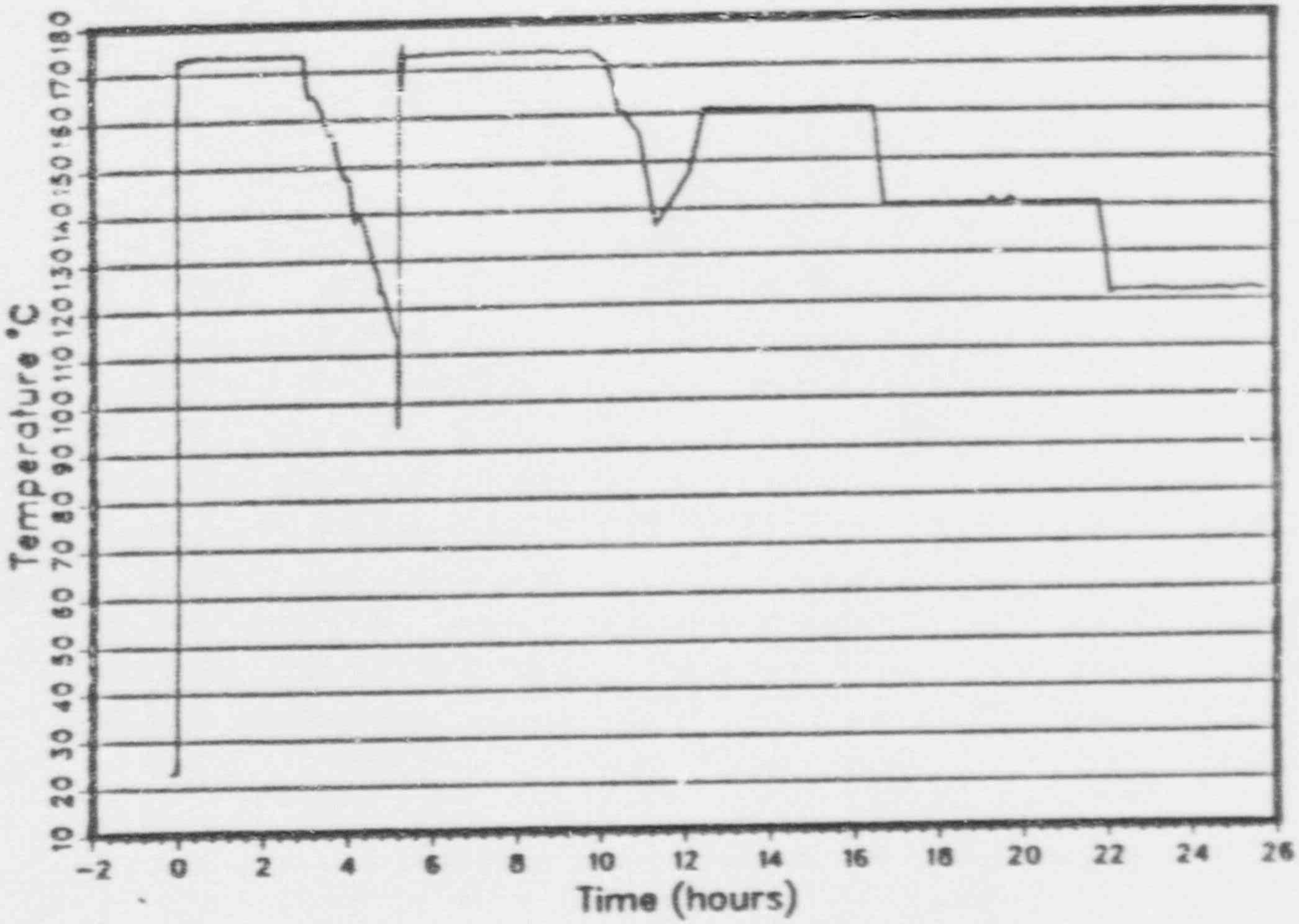


Figure 27

Figure T5-A-6

Trans. T5 First 26 hrs. Error Profile

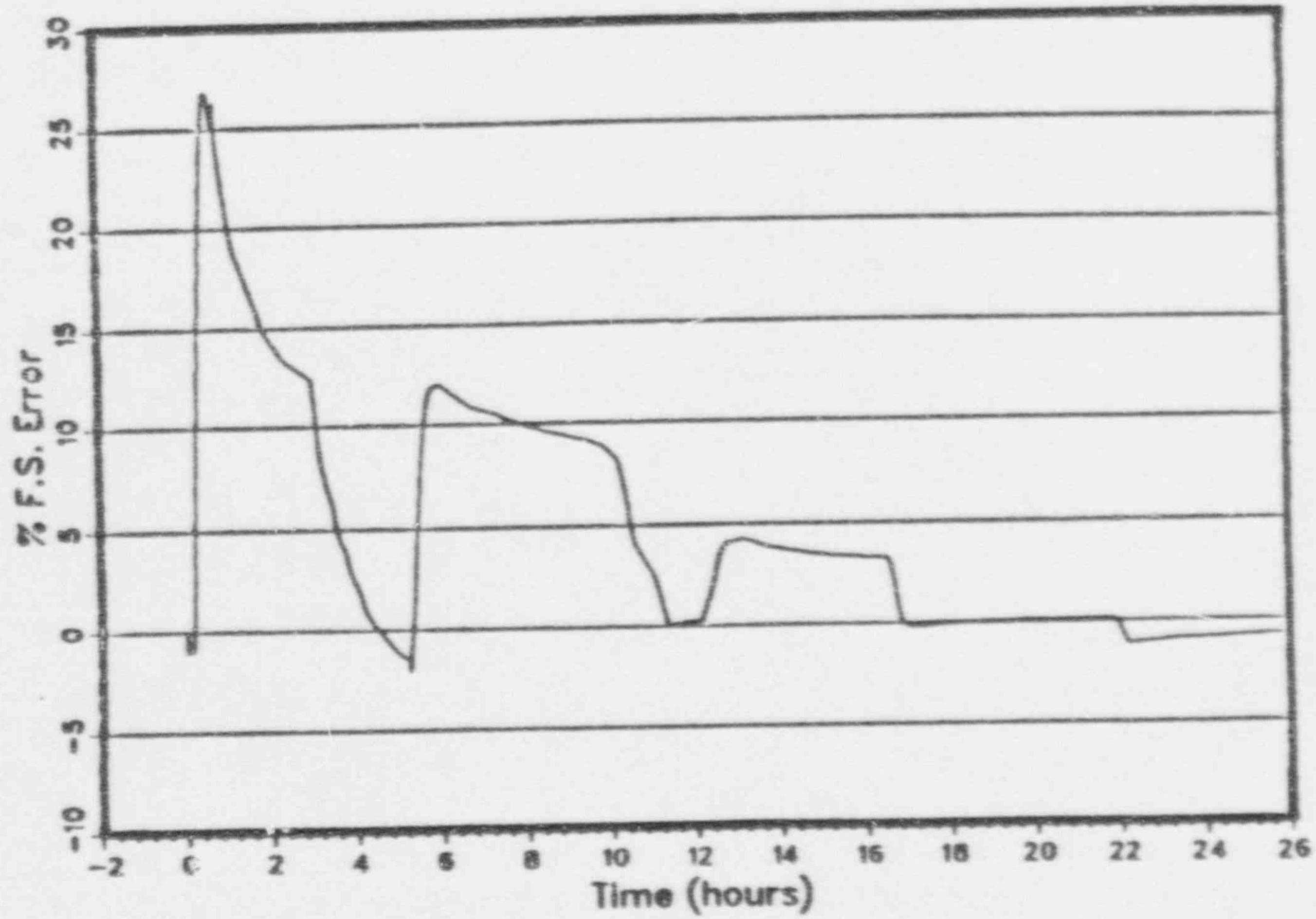


Figure 28

SYNERGISTIC EFFECTS, SEQUENCING EFFECTS, DOSE RATE EFFECTS, AND THE IMPORTANCE OF OXYGEN

We now want to discuss four related questions, namely:

1. How can the radiation aging environment be accelerated? Specifically, are dose rates an important consideration?

2. Are there synergistic effects between the aging environments that must be accounted for when developing the sequential test strategy?

3. Are there accident synergistic effects?

4. Is oxygen presence during an accident simulation important?

Technically, these four questions are related because of the importance of radiation, thermal, and oxygen environments to polymer degradation. The mechanistic degradation pathway is influenced by all three environments. Possibile manifestations of the mechanistic degradation include dose rate effects, aging synergistic and sequencing effects, accident synergistic effects, and oxygen effects during accident simulations.

From an inspection standpoint, these issues are much more difficult to deal with than is thermal aging. In one sense, the state of the art is not as advanced. For example, the Arrhenius technique has been in existence for a long time and is employed in non-nuclear IEEE standards. In contrast, industry wide knowledge of nuclear synergistic effects has not yet received institutional blessing. IEEE standards have been under development in the area of synergistic effects, but have not been published.

Before discussing the technical issues, let us review the regulatory guidance regarding these issues. 10 CFR 50.49 provides the following requirements:

Radiation. The radiation environment must be based on the type of radiation, the total dose expected during normal operation over the installed life of the equipment, and the radiation environment associated with the most severe design basis accident during or following which the equipment is required to remain functional, including radiation resulting from recirculating fluids for equipment located near the recirculating lines and including dose rate effects.

Synergistic Effects. Synergistic effects must be considered when these effects are believed to have a significant effect on equipment performance.
Reg Guide 1.89 (rev 1, June, 1984) states:

Electric equipment that could be exposed to radiation should be environmentally qualified to a radiation dose that simulates the calculated radiation environment (normal and accident) that the equipment should withstand prior to completion of its required safety functions. Such qualification should consider that equipment damage is a function of total integrated dose and can be influenced by dose rate, energy spectrum, and particle type....

> If synergistic effects have been identified prior to the initiation of qualification, they should be accounted for in the qualification program. Synergistic effects known at this time are dose rate effects and effects resulting from the different sequence of applying radiation and (elevated) temperature.

Now let us review the technical background for these technical issues. In general, synergistic effects, sequencing effects, dose rate effects, and oxygen effects are observed for some polymers. A simple representation for polymers is a plate of spagheti. Each spagheti noodle represents a polymer chain. Each polymer chain is characterized by the repeating chemical units that make up its length. For example, the backbone of polyethylene is the repeating unit ($-CH_2-CH_2-$). Other polymers have different repeating units. For example, polyvinylchloride replaces one of the H molecules in the polyethylene unit with a Cl molecule. In some cases such as ethylene propylene rubber, a simple side molecule such as H is replaced by a more complex molecule.

The long length of each spagheti noodle is responsible for some of the polymer's properties. For example, intertwining of many spagheti noodles makes it difficult to pick up just one with a fork. Mechanical properties of some polymers are similarly produced. Clearly, for this situation the length of each polymer chain is an important determinate of polymer properties. If a polymer chain is broken into smaller pieces by a radiation, thermal, or oxygen reaction, then mechanical properties will be changed.

For some polymers, the spagheti noodles are randomly bonded to each other at various locations along their lengths. This process is known as cross-linking. For a cross-linked polymer, no one polymer chain can be separated from another since they are all bonded together. The two major cable insulations currently being employed in nuclear installations are cross-linked polymers, namely ethylene propylene rubbers and cross-linked polyolefins.

The mechanical properties of cross-linked polymers depends on two properties, the cross-link density and the length of the polymer chains. (In one sense it may be difficult to differentiate between these two concepts). If a polymer chain or coss-link is broken by radiation, thermal, or oxygen environments, then mechanical properties will be modified. Synergistic effects, dose rate effects, and sequencing effects are manifestations of the interactive nature of radiation, thermal, and oxygen influence on polymer chain breakage.

In this course we cannot spend the necessary time to explain the chemistry of this interaction between oxygen, radiation, and thermal environments. Rather, let us discuss and illustrate the empirical manifestations:

1. Oxygen presence is important to polymer chain scission degradation when either thermal or radiation environments are present. At high dose rates (of the order of 1 Mrd/h) the initial oxygen concentration in the polymer is depleted in less than 1 Mrd. Hence the replenishment of oxygen depends on the oxygen diffusion rate and its relationship to the dose rate. In the regime where oxygen concentration is diffusion limited, dose rate effects may occur. This is demonstrated for PVC in Figure 29. Note the plateau that develops at approximately 300 Gy/h (30 krd/h) at 43 C irradiations. Above this dose rate, degradation is oxygen diffusion limited and dose rate effects occur.

   One method for dealing with this effect is used by the French in their qualification efforts. The French require that aging irradiations be at dose rates less than 150 krd/h. The minimum allowable value is 50 krd/h. In the U.S. many generic qualification efforts use a 50 Mrd aging dose. At a maximum value of 150 krd/h, this 50 Mrd irradiation would require a 14 day exposure.

2. Figure 29 illustrates another dose rate mechanism at low dose rates (i.e., at 45 C for dose rates below approximately 30-40 Gy/h (3-4 krd/h)). This mechanism is caused by breakdown of hydroperoxides within the polymer. Theoretical and experimental efforts regarding this breakdown mechanism result in Figure 30 for PVC. In this figure the required dose to achieve equivalent damage is plotted at several dose rates. Note that at high dose rates an order of magnitude increase in total dose is required to achieve the same degradation as is obtained at low dose rates.

   The data of figures 29 and 30 are for PVC. This material is no longer commonly used inside containment. Its value is that long term natural aging data (i.e., 14 years) is available and hence correlation between theoretical acceleration techniques and actual experience is possibile. The correlation is excellent in this case.

   The hydroperoxide breakdown effect can maniflest itself in another form besides dose rate effects. It may sometimes be responsibile for sequencing or synergistic effects. In particular, when hydroperoxide breakdown is important, radiation aging prior to thermal aging will be more severe. The hydroperoxide effect has has been clearly demonstrated to cause sequencing effects for PVC and LDPE. Other materials exhibiting aging sequencing effects include EPR's, Chlorosulfonated polyethylene (HYPALON), chemically cross-linked polyethylene, and chlorinated polyethylene.

3. Another manifestation of oxygen's importance to polymer degradation occurs during LOCA simulations. Figures 31-34 illustrate Japenese data suggesting the importance of oxygen. Note that degradation is typically more severe when oxygen is included in the LOCA simulation. Additional results regarding this issue were obtained during U.S.-French cooperative experiments that have been performed during the last few years. Some results are illustrated in Figures 35-39 and provided in Tables 11-12. EPR, TEFZEL, and Chloroprene rubber (Neoprene) materials are examples where degradation is enhanced when air (oxygen) is present during accident simulations. The U.S. cross-linked polyolefin materials are examples where degradation of tensile elongation was reduced when air was present during LOCA simulations.

4. The interaction of radiation, thermal, and oxygen environments (presence or depletion) can also give rise to accident synergistic effects. Numerous examples have been provided in Figures 31-39 and Tables 11-12 that have been previously shown.

These results clearly demonstrate that for some materials dose rate effects, sequencing effects, synergistic effects, and oxygen presence are important to the mechanical degradation of polymer materials. For other materials such effects have not been noted. Unfortunately, the influence of dose rate effects, etc, may not be uniform within a "generic" polymer classification. For example, EPR insulations are typically only 40 % by weight EPR polymer. Each manufacturer adds a collection of clays, antioxidants, fillers, and possibily fire-retardants to the EPR polymer to form an EPR insulation. These additional constituents can be very important in establishing the insulation's properties, particularly with respect to dose rate effects, synergistic effects, etc. Developing an insulation or polymer formulation is truly a "black art". As such it is appropriate that the qualification process design verify the "black art" product.

Table 13 provides a partial chronological history of the development of a "synergistic and dose rate" data base in the public literature. Applicable conclusions of each publication for materials studied is also provided. This list when combined with Reg Guide 1.89's guidance provides a basis for inspection. Note, Reg Guide 1.89 states:

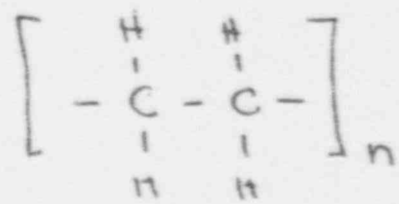
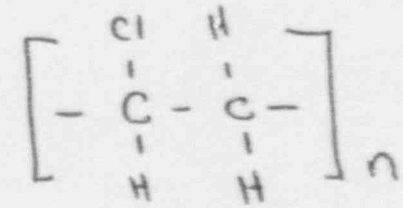
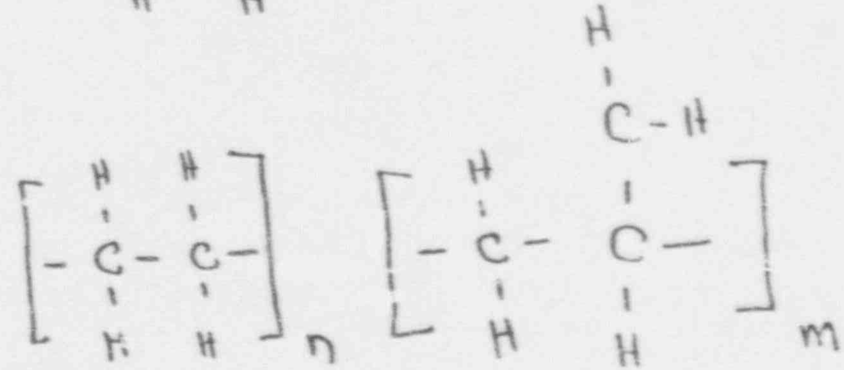
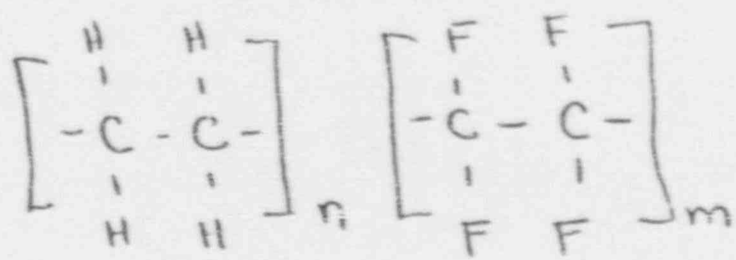
> "If synergistic effects have been identified prior to the initiation of qualification, they should be accounted for in the qualification program. Synergistic effects known at this time are dose rate effects and the effects resulting from the different sequence of applying radiation and (elevated) temperature."

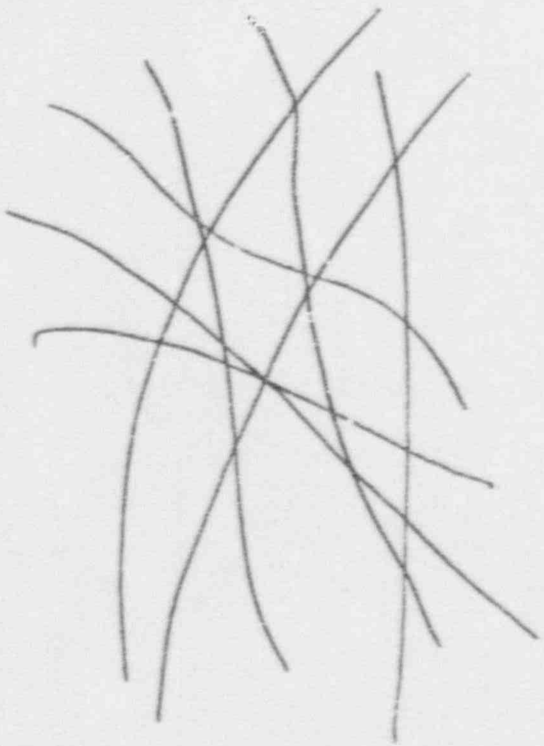
Thus based on the date of the qualification effort it should reference applicable literature from Table 13. If not, a nonconformance against Reg Guide 1.89 may be possible (Note, many purchase orders to manufacturers will list Reg Guide 1.89 as an applicable document. Hence a nonconformance via criteria 5 of 10 CFR 50, Appendix B may be possibile. We will discuss the mechanics of an inspection in more detail later.)

It is important to recognize that initially the nonconformances should be for failure to analyze published literature applicable to the qualification effort.

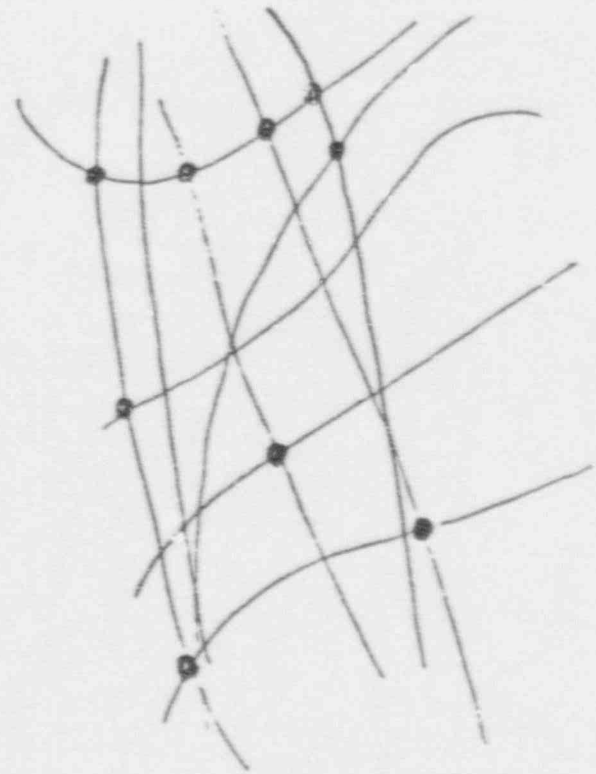
There is an additonal inspection basis when electical wiring is involved (such as leads to a pressure switch, electrical cabling, etc). IEEE Std 383-1974 in section 2.3.3.3 states that dose rates greater than 1 Mrd/h shall not be employed. If a test plan or test report references aging radiation dose rates in excess of 1 Mrd/h without explanation, then consideration of dose rates appears to have been ignored. A nonconformance may be warrented.

There is the potential for confusion with the current wording of Reg Guide 1.89's guidance with respect to synergistic effects. Namely, Reg Guide 1.89 states in part "if synergistic effects have been identified prior to the initiation of qualification...." This needs further clarification. Many manufacturers perform generic qualification tests and then analyze their results to meet the needs of specific purchase orders. Is the initiation of qualification the initiation of the original qualification test activity or the initiation of analysis to demonstrate compliance with the purchase order?

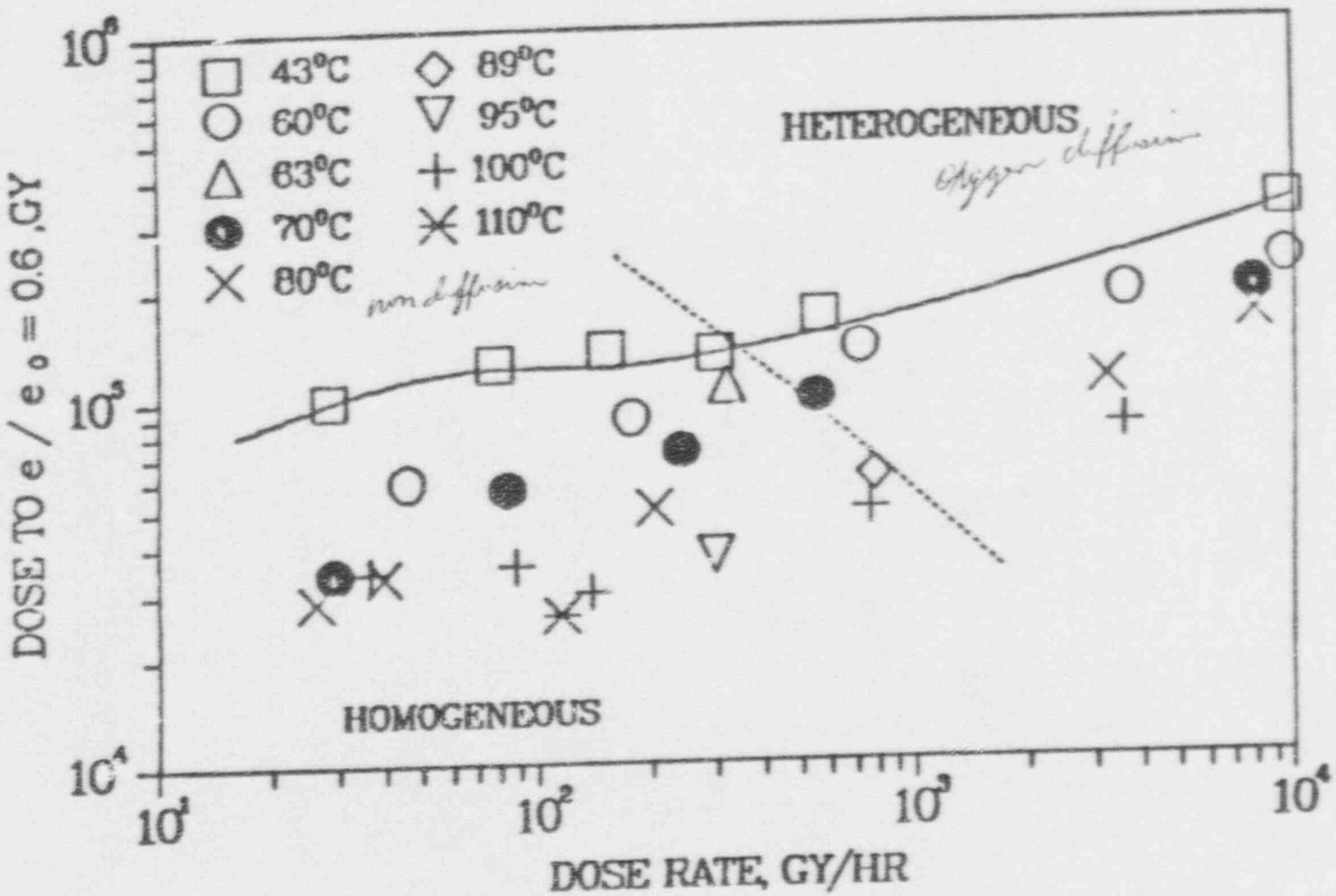
Name	Repeating Chemical Unit
1. Polyethylene	
2. Polyvinylchloride (PVC)	
3. Ethylene Propylene Rubber	
4. TEFZEL	



Thermoplastic



Cross-linked ; Thermoset



43°C
60°C
63°C
70°C
80°C
89°C
95°C
100°C
110°C
HETEROGENEOUS
HOMOGENEOUS
DOSE TO e / e₀ = 0.6 ,GY
DOSE RATE, GY/HR
10⁶
10⁵
10⁴
10¹
10²
10³
10⁴

Figure 29

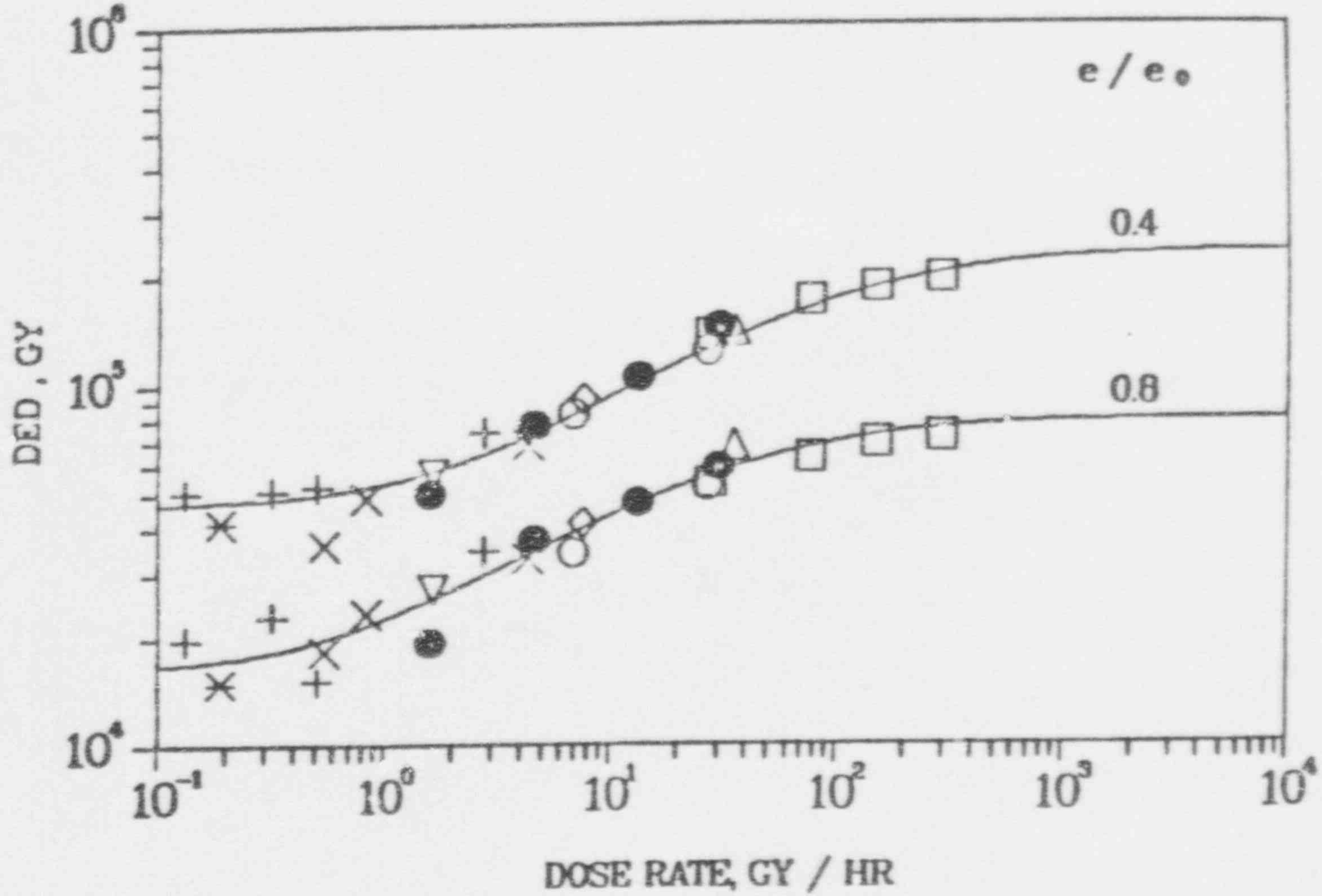
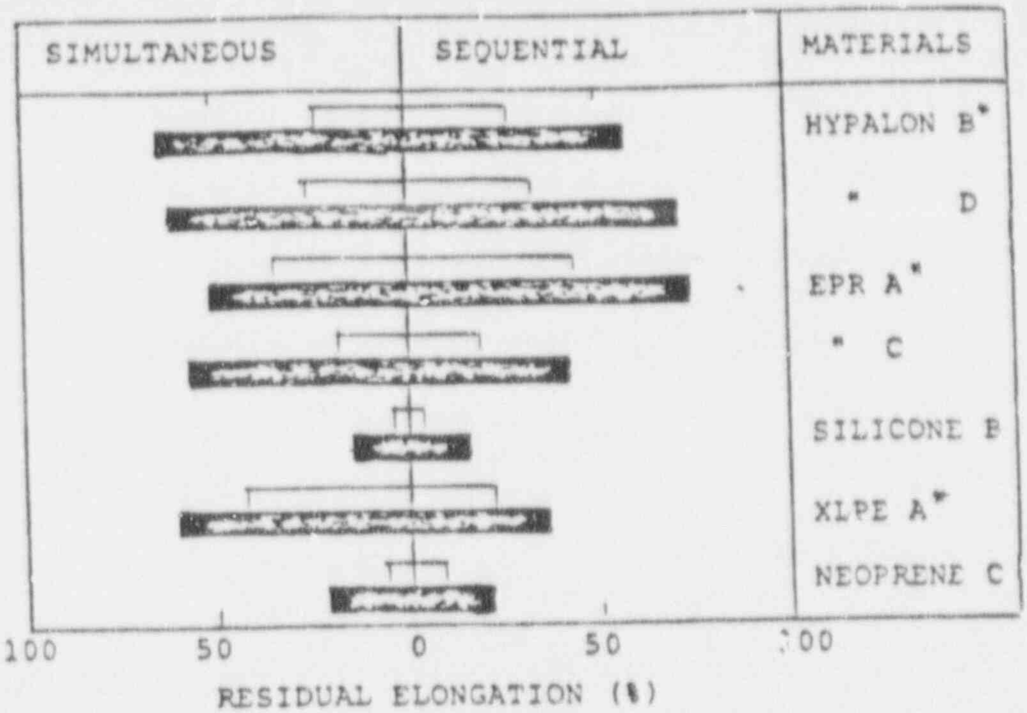

e/e₀
0.4
0.8
DED, GY
10⁶
10⁵
10⁴
10⁻¹
10⁰
10¹
10²
10³
10⁴
DOSE RATE, GY / HR

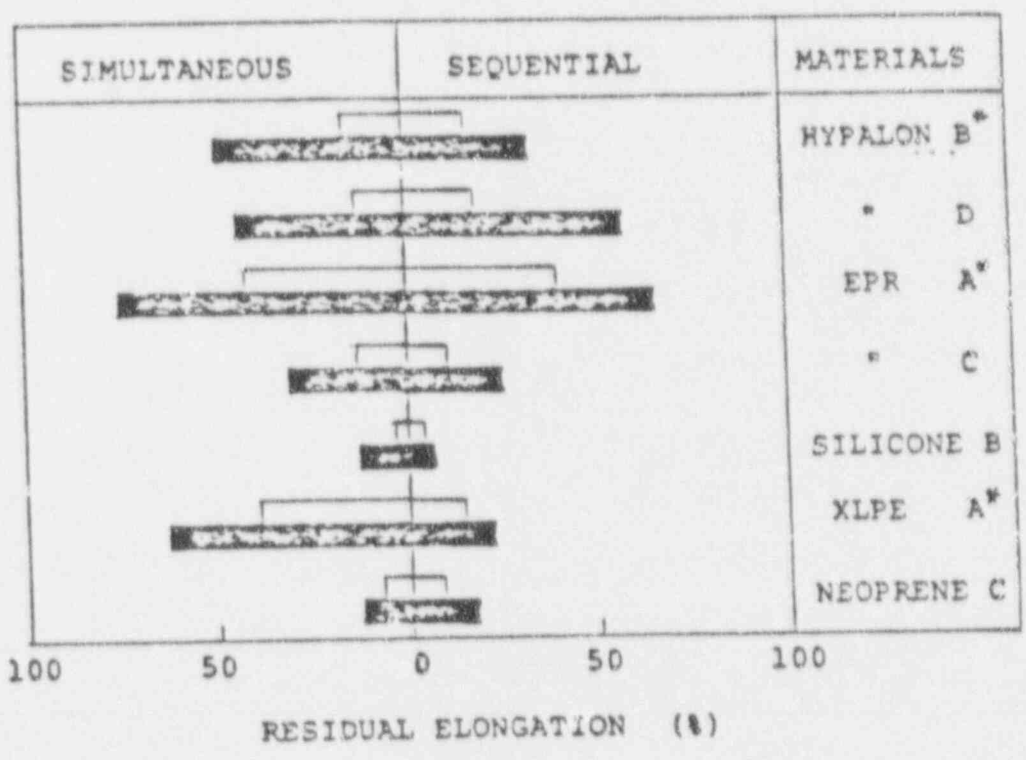
Figure 30



Comparison of mechanical properties of the materials after simultaneous and sequential LOCA testing (BWR conditions).

▭ ; Pre-conditioned

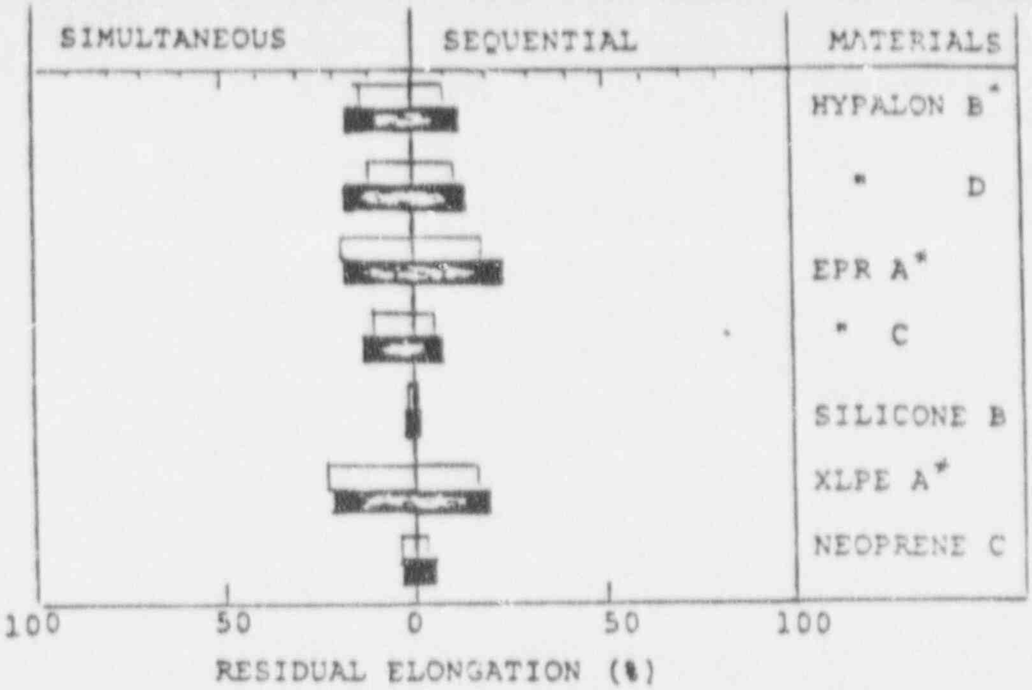
▬ ; Not pre-conditioned



Comparison of mechanical properties of the materials after simultaneous and sequential LOCA testing (BWR conditions containing air).

▭ ; Pre-conditioned

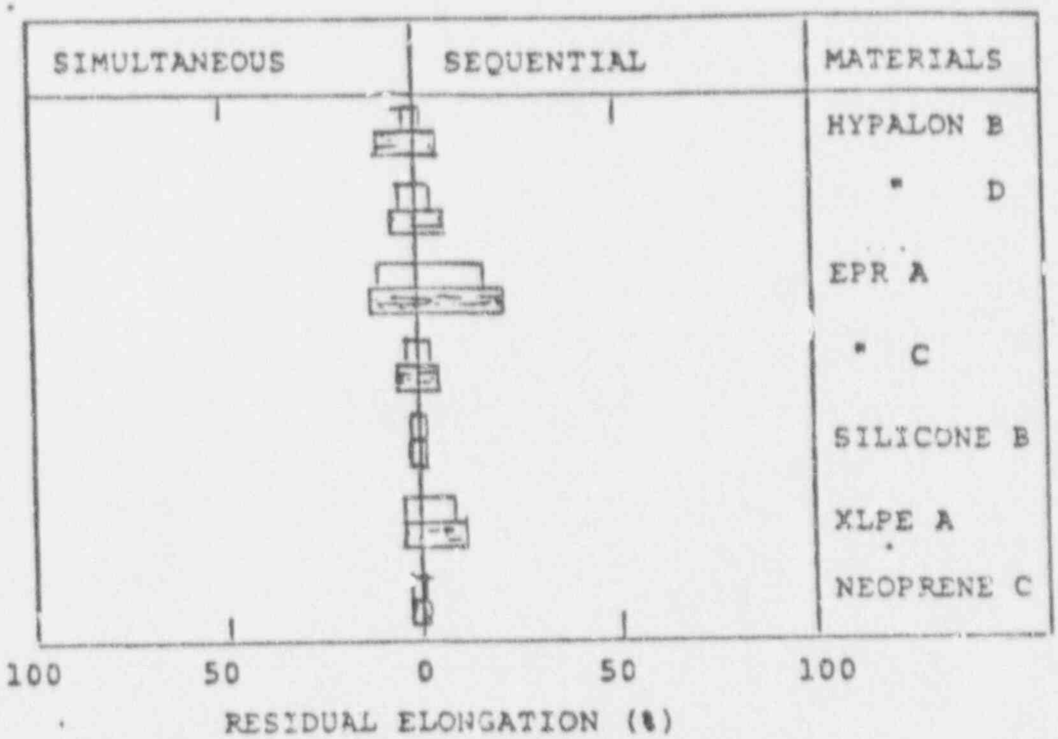
▬ ; Not pre-conditioned



Comparison of mechanical properties of the materials after simultaneous and sequential LOCA testing (PWR conditions).

☐ ; Pre-conditioned

■ ; Not pre-conditioned



COMPARISON OF MECHANICAL PROPERTIES OF THE MATERIALS AFTER SIMULTANEOUS AND SEQUENTIAL LOCA TESTING (PWR CONDITIONS CONTAINING AIR)

☐ PRE-CONDITIONED

■ NOT PRE-CONDITIONED

Figures 33 - 34

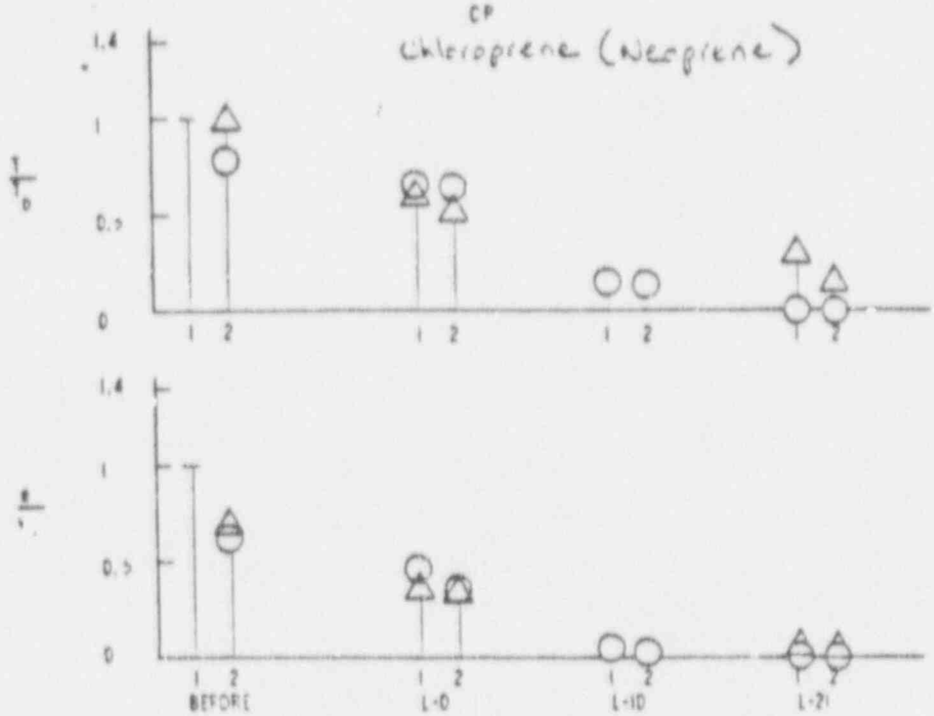


Fig. 10. Tensile property results for CP. See the caption for fig 4 for explanation.

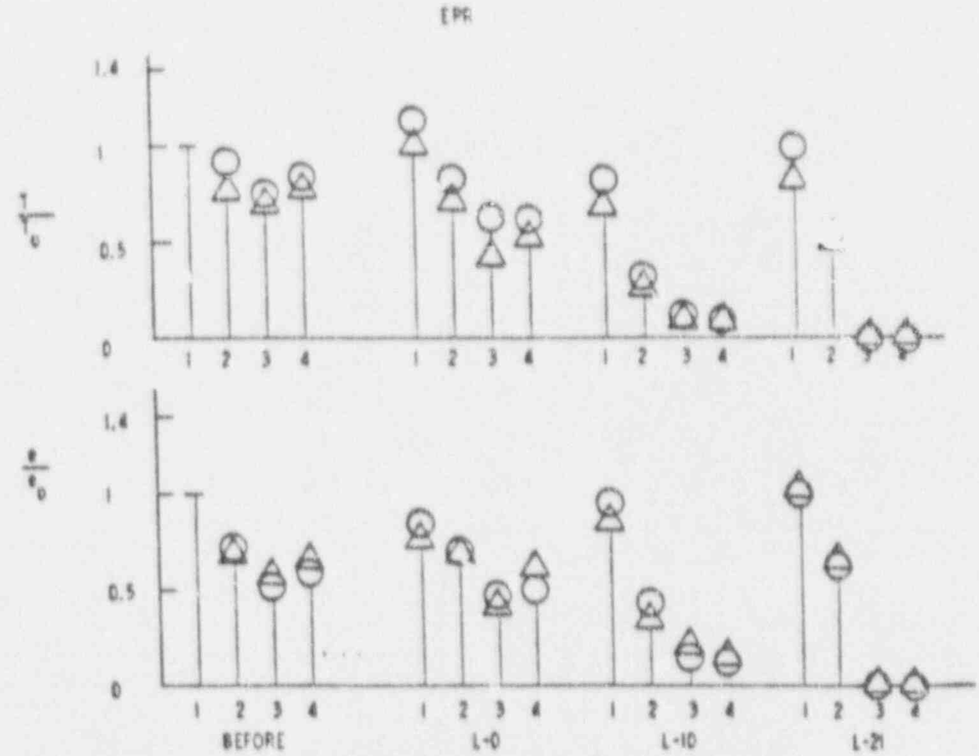


Fig. 11. Tensile property results for EPR. See the caption for fig 4 for explanation.

Figure 35

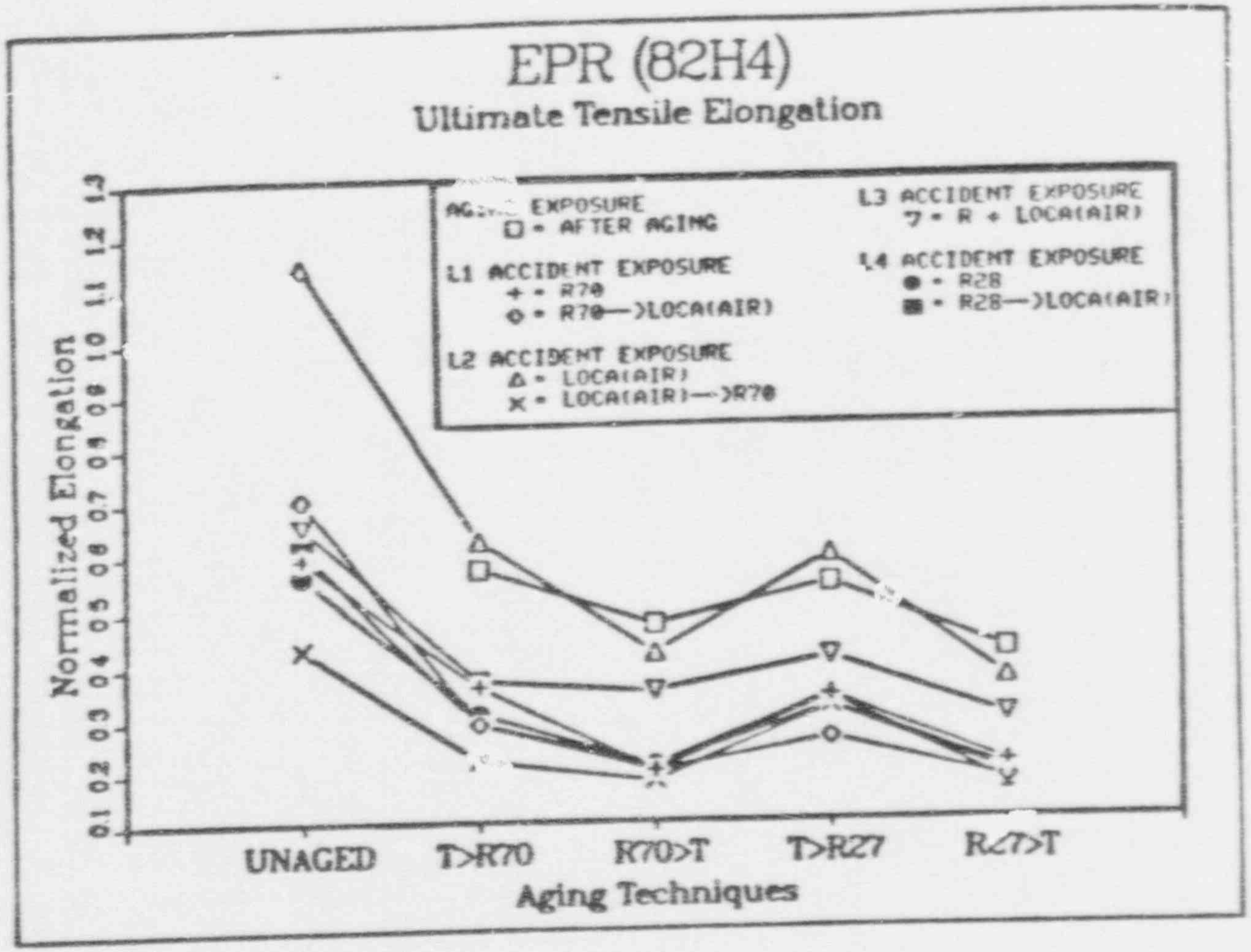
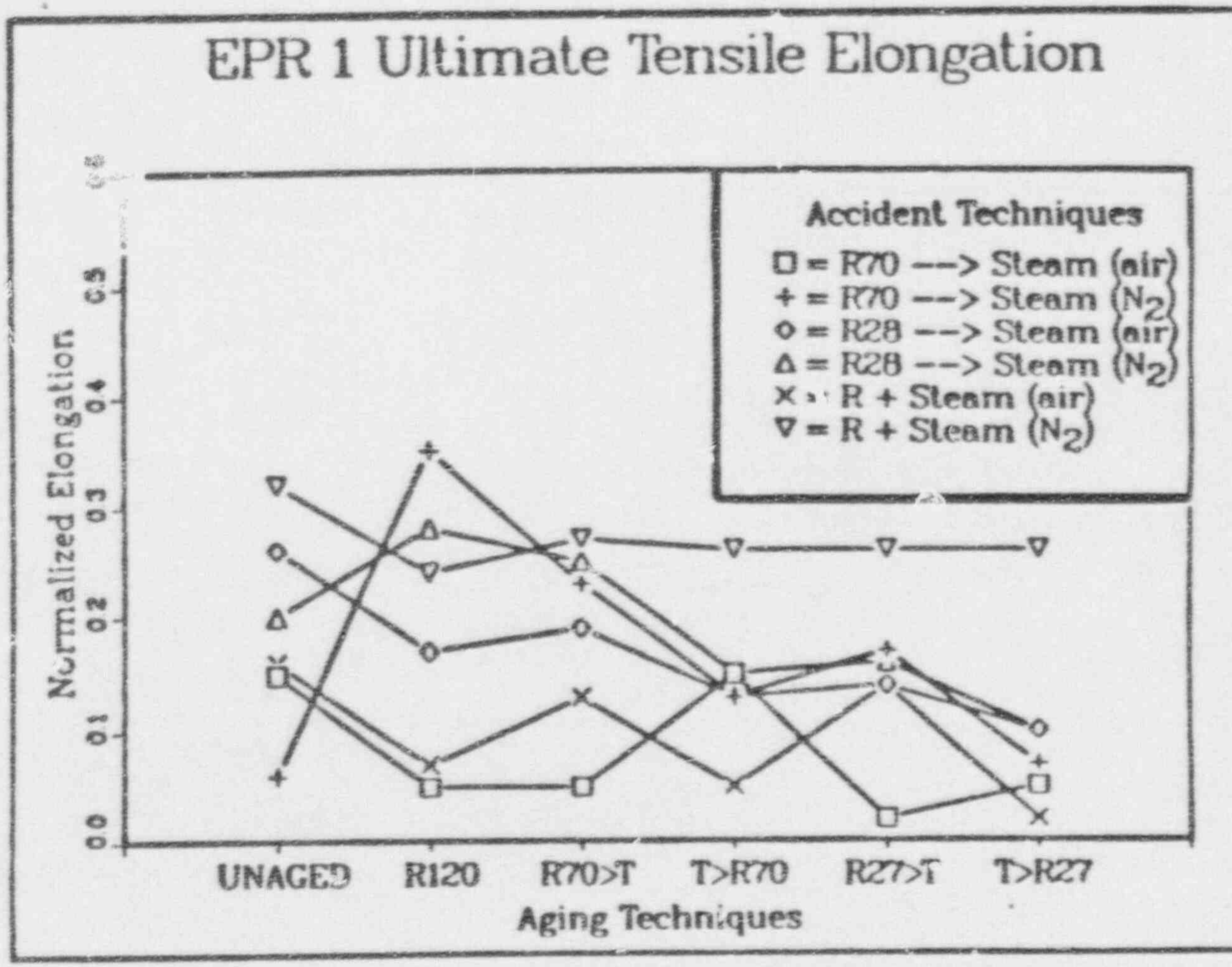

EPR (82H4)
Ultimate Tensile Elongation
Normalized Elongation
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
EXPOSURE
□ = AFTER AGING
L1 ACCIDENT EXPOSURE
+ = R70
◇ = R70—>LOCA(AIR)
L2 ACCIDENT EXPOSURE
Δ = LOCA(AIR)
X = LOCA(AIR)—>R70
L3 ACCIDENT EXPOSURE
▽ = R + LOCA(AIR)
L4 ACCIDENT EXPOSURE
● = R28
■ = R28—>LOCA(AIR)
UNAGED
T>R70
R70>T
T>R27
R<7>T
Aging Techniques

Figure 36



EPR 1 Ultimate Tensile Elongation
Accident Techniques
□ = R70 --> Steam (air)
+ = R70 --> Steam (N2)
◇ = R28 --> Steam (air)
Δ = R28 --> Steam (N2)
× = R + Steam (air)
∇ = R + Steam (N2)
Normalized Elongation
0.0
0.1
0.2
0.3
0.4
0.5
UNAGED
R120
R70>T
T>R70
R27>T
T>R27
Aging Techniques

Figure 37

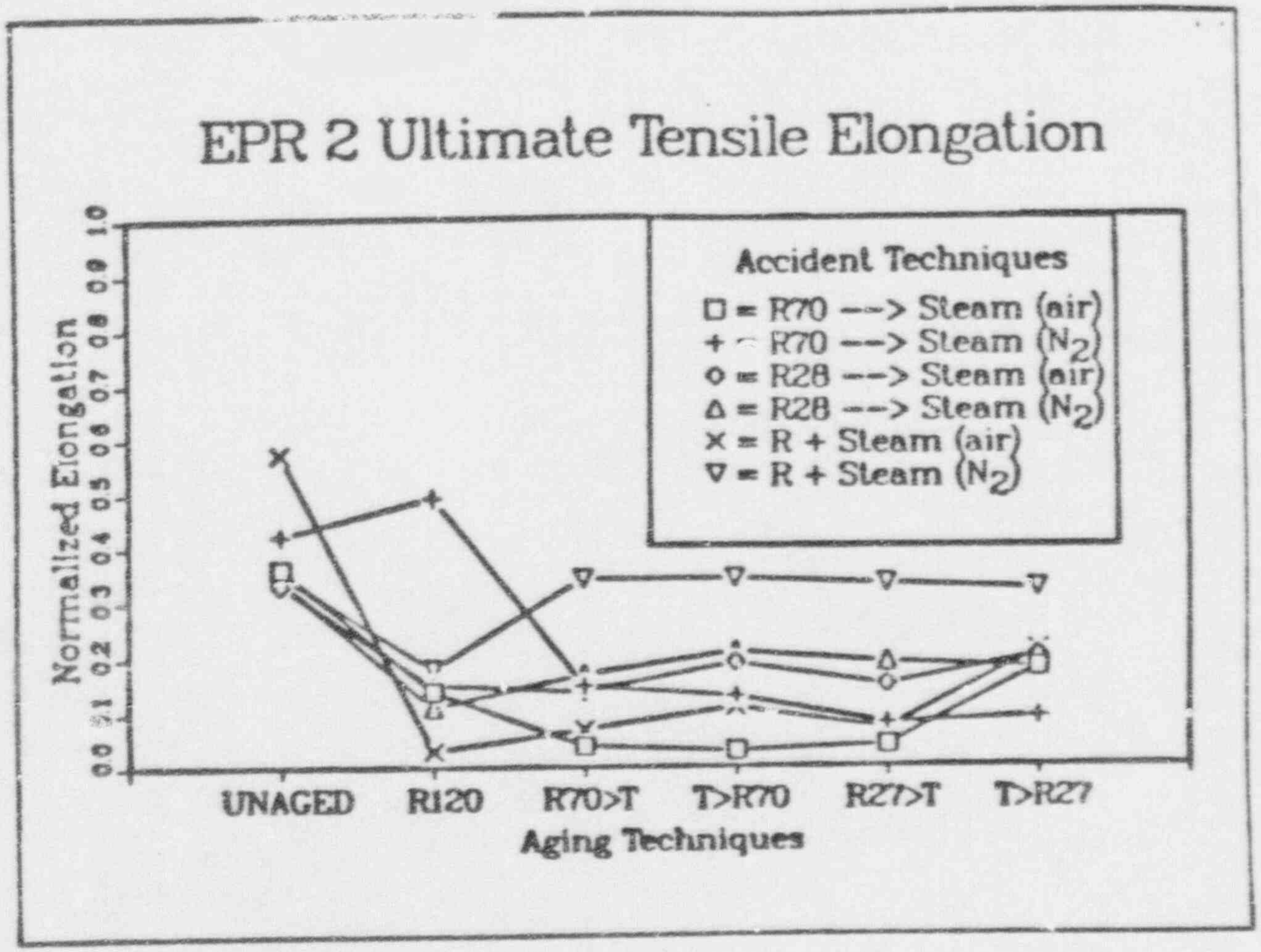

EPR 2 Ultimate Tensile Elongation
Accident Techniques
□ = R70 --> Steam (air)
+ = R70 --> Steam (N2)
◇ = R28 --> Steam (air)
Δ = R28 --> Steam (N2)
× = R + Steam (air)
▽ = R + Steam (N2)
Normalized Elongation
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
UNAGED
R120
R70>T
T>R70
R27>T
T>R27
Aging Techniques

Figure 38

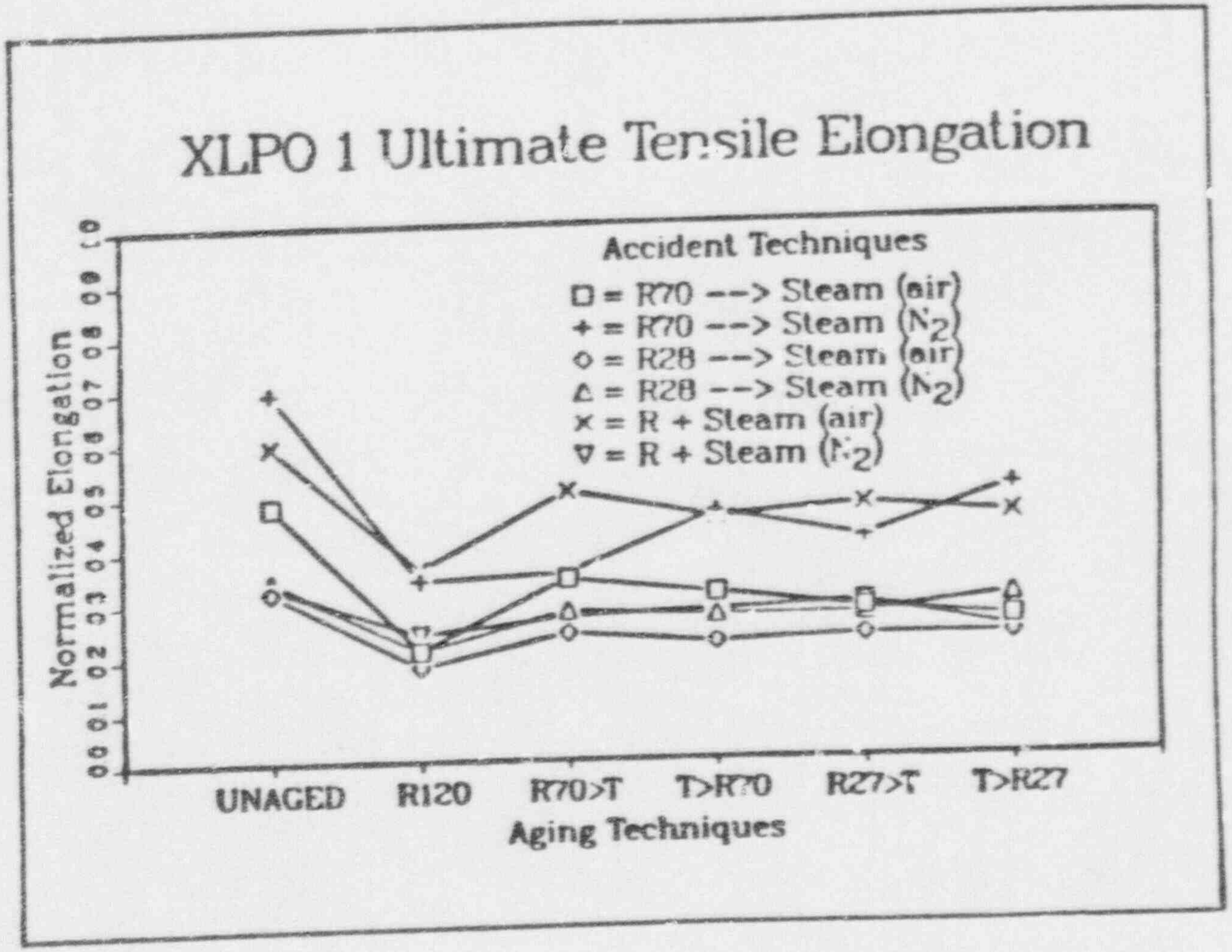

XLPO 1 Ultimate Tensile Elongation
Accident Techniques
□ = R70 --> Steam (air)
+ = R70 --> Steam (N2)
◇ = R28 --> Steam (air)
Δ = R28 --> Steam (N2)
× = R + Steam (air)
∇ = R + Steam (N2)
Normalized Elongation
UNAGED
R120
R70>T
T>R70
R27>T
T>R27
Aging Techniques

Figure 39

a. TEFZEL 2: Largest Bend Radii At Which One Sample Cracked. Table entries are expressed as multiples of the TEFZEL 2 radius.

ACCIDENT SIMULATIONS

Aging Technique	R70→ST(AIR)	R70→ST(N_2)	R28→ST(AIR)	R28→ST(N_2)	R + ST(AIR)	R + ST(N_2)
UNAGED	11.00	6.00			75.00	
R120	75.00	75.00	75.00	75.00	75.00	75.00
R70→120	75.00	75.00	75.00	75.00	75.00	75.00
120→R70	75.00	75.00	75.00	75.00	75.00	75.00
R27→120	22.00	44.00	22.00	22.00	75.00	44.00
120→R27	75.00	31.00	22.00	31.00	75.00	69.00

b. TEFZEL 2: Radii By Which All Samples Cracked. Table entries are expressed as multiples of the TEFZEL 2 radius.

ACCIDENT SIMULATIONS

Aging Technique	R70→ST(AIR)	R70→ST(N_2)	R28→ST(AIR)	R28→ST(N_2)	R + ST(AIR)	R + ST(N_2)
UNAGED	6.00	6.00			75.00	
R120	75.00	75.00	75.00	75.00	75.00	75.00
R70→120	75.00	75.00	44.00	75.00	75.00	56.00
120→R70	22.00	75.00	75.00	56.00	75.00	75.00
R27→120	11.00	11.00	11.00	11.00	75.00	22.00
120→R27	22.00	11.00	11.00	22.00	75.00	44.00

Tables 11-12

How does one simulate beta and gamma radiation environments?
How do you account for beta shielding effects?

Radiation environments for primary and secondary containment of Limerick's BWR/4 Mark II were previously presented in Table 4. For both locations unshielded beta doses are at least an order of magnitude higher than are gamma doses. WCAP-8587 for Westinghouse PWRs also indicates an order of magnitude higher beta dose than gamma dose. These beta doses should be accounted for during qualification activities. Reg Guide 1.89 states:

"Such qualification should consider that equipment damage is a function of total integrated dose and can be influenced by dose rate, energy spectrum, and particle type."

One approach to beta doses is shielding. Reg Guide 1.89 states:

"Shielded components need be qualified only to the gamma radiation environment provided it can be demonstrated that the sensitive portions of the component or equipment are not exposed to significant beta radiation dose rates or that the effects of beta radiation, including heating and secondary radiation, have no deleterious effects on component performance. If, after considering the appropriate shielding factors, the total beta radiation dose contribution to the equipment or component is calculated to be less than 10% of the total gamma radiation dose to which the equipment or component has been qualified, the equipment or component is considered qualified for the beta and gamma radiation environment."

When shielding has been employed to account for beta doses, the following inspection questions are applicable.

1. Has the shielding been installed at all important locations, particularly at interfaces. For example, is there shielding between the cable conduit and the instrument housing of a Class 1E component?

2. Is the shielding appropriate? For example, cable jacket material may not survive a 1000 Mrd beta dose. Hence, for the later stages of an accident, the jacket may not be providing the assumed shielding.

3. The shielding may heat up due to beta radiation. Has this been accounted for during the qualification analysis.

4. Was plant specific analysis used to justify any reductions in dose or dose rate resulting from component location or shielding? This is a "requirement" of Reg Guide 1.89.

Recent research suggests that a previous additional concern may not be important. Electron charge buildup due to beta radiation on insulation surfaces does not appear to be a problem.

A second approach to beta radiation is also typically used by industry. It is assumed that beta radiation effects on material properties can be simulated with an equivalent gamma dose. Reg Guide 1.89 states:

> "Cobalt-60 or cesium-137 would be acceptable gamma radiation sources for environmental qualification."

What is unclear in this statement is whether Co-60 or Ce-137 are acceptable for beta simulation. NUREG-0588, rev 1 clarified this subject in its Response to Comments section:

> "... there does not seem to be any significant problem in using only a gamma source to qualify certain types of equipment for a beta/gamma environment provided the gamma dose rate during the qualification tests is consistent with the expected beta and gamma dose rates (energy deposition rates) during LOCA. It appears therefore that a gamma source (only) may be used for qualification testing, provided an analysis or test data indicates that the dose and dose rate produces damage similar to that which could be produced under accident exposure (i.e., combined gamma and beta environment)..."

The issue of beta-gamma equivalence is currently a reseach activity in the NRC research program.

What are relevant post-accident acceleration techniques? What analysis is necessary to claim that a generic environmental profile is acceptable for a plant specific application?

Sometimes manufacturers will perform a generic qualification test prior to marketing a product. Then, in response to a purchase order, analysis is performed to justify the applicability of the generic effort to plant specific requirements. Frequently the generic profile is similar to the Appendix B profile of IEEE Std. 323-1974. This profile does not envelope the initial tempertures of MSLB test conditions. Also, test duration is typically not as long as the purchase order specification. A second related situation occurs during the development of qualification test strategy. Some Class 1E equipment must operate for long periods after the start of an accident (for example, 1 year). It may not be viable to perform a one year accident simulation. A reasonable question is how to deal with these situations on an inspection.

Let us start by reviewing industry practice. Frequently the Arrhenius equation is invoked. For example, a one year accident simulation may be shortened by raising the accident simulation temperature and shortening the time exposure. The Arrhenius equation is employed to calculate appropriate "shortened" test conditions. In the case where a test has already been performed, say for one month, but a purchase requirement is for one year, the Arrhenius equation is invoked in reverse. For example, the purchase specification may require a 10 minute exposure to 340 F while the specimen was actually exposed for 3 hours. The Arrhenius equation is then used to argue that the additional 2 hour, 50 minute exposure at 340 F is equivalent to a much longer time at say 150 F. By adding up such additional increments, assertion is made that the purchase order requirement is satisfied.

A second variation of this arguement is to use LOCA test data and the Arrhenius technique to argue that qualification for the initial high temperatures of a MSLB have been satisified. For example, an arguement may be made that 3 hours at 340 F is more severe than 15 minutes at 385 F. This arguement should rarely be accepted without more substantial analysis. It is also unclear whether any analysis is currently acceptable in lieu of MSLB testing. More about this when we consider the applicable regulations.

Next, let us look at the technical aspects of these practices. The Arrhenius equation describes acceleration of chemical reaction rates that may ultimately give rise to macroscopic material changes. Years of industry experience suggest its applicability in thermal environments. There is not a very large data base indicating its applicability for steam environments. Some data published in SAND82-1071 suggests that degradation of many polymers in steam environments (with air) is similar to degradation in a thermal environment. Thus one might argue that the Arhenius equation is also applicable to steam environements. Research by the Naval Research Laboratory (NRL Memorandum Report 5158, August, 1983) indicates that KAPTON degradation in heated water is Arrhenius. Hence to accelerate long term materials degradation in post-accident environments, the Arrhenius technique can probably be considered current state-of-the-art. However, there are some limits to its use that need to be considered.

1. The activation energy in a steam environment may differ compared to the activation energy for a hot air environment. For example, the EPRI draft Equipment Qualification Data Bank lists seven references for polyimide or polyimide/glass. Activation energies vary from .87 eV to 1.68 eV. The NRL report reports an activation energy of .6 eV for a heated water exposure. Hence, conservative choices for activation energy may be warrented for post accident acceleration techniques. Westinghouse's WCAP-8587 suggests that a conservative value of .5 eV will be employed for post accident acceleration.

2. Insure that the acceleration is not overly ambitious. For example, it may not be wise to reduce a one year requirement to a 2 day test exposure unless substantial supporting data and analysis is available. WCAP-8587 describes Westinghouse's program for post-accident acceleration. A 15 day test is employed to simulate a 4 month requirement. A 29 day test is used to simulate a one year requirement.

3. Insure that failure modes or degradation mechanisms are not masked by the acceleration process. For example, increasing the temperature without consideration of the pressure may

   a. create superheat conditions and possibily mask failure modes associated with moisture condensation.

   b. reduce oxygen presence in the test chamber and hence reduce oxygen dominated degradation.

4. The Arrhenius technique may not accelerate moisture intrusion processes. One test laboratory we visited during our inspections combined the Arrhenius technique with temperature, humidity cycling to generate a post-accident acceleration process.

5. Long term materials degradation may not be the only failure mode for a piece of equipment. For example, temperature effects may be important. Hence, be wary of qualification analysis that attempts to use LOCA test data and Arrhenius techniques to satisfy MSLB test requirements. (We will discuss this issue further in a minute.)

Now that we have reviewed some industry practices as well as some of the technical issues, let us review the NRC guidance.

NRC guidance concerning these practices is as follows. Reg Guide 1.89 states:

> "Since the test profiles included in Appendix A to IEEE Std 323-1974 are only representative, they should not be considered an acceptable alternative to using plant-specific containment temperature and pressure design profiles unless plant-specific analysis is provided to verify the applicability of those profiles."

This is the extent of current NRC guidance regarding post-accident acceleration and the use generic test profiles to satisfy different plant-specific profiles. NUREG-0588 previously provided additional guidance that is no longer mentioned in revision 1 of Reg Guide 1.89. For example, NUREG-0588 specifically discussed the case where LOCA qualification had been completed but MSLB conditions had not been considered. The thrust of the requirement was that equipment temperatue response to the MSLB conditions had to be evaluated. If the maximum LOCA test conditions were never exceeded, then the previous LOCA testing was acceptable. If calculations indicated that the LOCA temperatures would be exceeded by the equipment, then either retesting or protective coverings were required.

ADDITIONAL QUESTIONS

We have examined several of the test simplification questions. Let us quickly review the remaining questions.

Must the effects of dust be considered in the aging program?

NUREG-0588 originally required that "dust environments should be addressed when establishing qualification service conditions". In response to public comment on NUREG-0588, the revision 1 Appendix stated:

> "It is not the staff's intent to require quantitative testing to ensure equipment operability in dusty environments, but rather to highlight a potential failure mechanism. Equipment susceptability to dust should be considered when qualifying safety-related equipment and be accounted for in the interface requirements via, for example, in improved periodic maintenance, or by the use of protective covers. The staff is currently in the process of rulemaking and will consider the recommendations in the above comments, in the "Final" position."

The final rulemaking (10 CFR 50.49) does not explicitly mention dust as an environnment that must be considered during qualification. Reg Guide 1.89 also doesn't mention dust in Section C, "Regulatory Position". In Section B, "Discussion", accumulation of deposits is mentioned as a process or environmental factor that could result in degradation and the Reg Guide appears to recognize that state-of-the-art preconditioning techniques may not be available.

Must the effects of mechanical cycling be considered in the aging program? Can the mechanical cycling requirements be reduced?

Reg Guide 1.89 endorses and supplements IEEE Std. 323-1974. Section 6.3.3 of IEEE Std. 323-1974 states:

> "Electromechanical equipment (motors, relays, etc) shall be operated to simulate the expected mechanical wear and electrical contact degradation (for example, contact pitting) of the device to be type tested.
>
> An accelerated rate for the number of cycles equal to the required number during the design life may be utilized provided the rate shall not be accelerated to any value which results in effects that would not be present at normal rates."

Hence, mechanical cycling is required and may be accelerated. There are two industry practices that you may encounter.

1. IEEE Std. 382-1980 requires a minimum of 10 percent of the required mechanical wear aging operating cycles to be

performed under load during the aging period. For IEEE Std. 382-1980, the recommended aging temperature is 138 C. Franklin Research Center performed research testing on several value actuators as part of an NRC research program. They conclude that "operational cycling at the elevated thermal aging temperature may have produced stresses not representative of in-service use.

2. Non-typical pressure gases may be employed during qualification testing to actuate values, etc. For the above mentioned Franklin research test on valve actuators, Franklin concludes "the use of nitrogen to pressurize the values during thermal aging severly inhibited the aging process since the majority of EPDM components were blanketed in nitrogen".

Should the accident simulation account for radiation dose rate effects?

Reg Guide 1.89 indicates that

"qualification should consider that equipment damage is a function of total integrated dose and can be influenced by dose rate, energy spectrum, and particle type".

There are two issues here. As discussed for aging, dose rate effects may contribute to long term materials degradation that may eventually lead to failure. A second issue is whether the initial high accident dose rates may momentarily cause electical equipment such as transmiters to fail. Note, typically, these sensitive items may be shielded from beta radiation effects.

Can saturated steam conditions be employed instead of superheated steam?

Table A2 of Appendix A of Std. 323-1974 states:

"If it is not practical to reproduce the specified pressure and temperatue profiles combined, it is acceptable during the first four days to follow the temperature profile and allow the pressure to conform to saturated conditions (100 percent relative humidity). This procedure is justified by the fact that temperature is the most important parameter and increasing the pressure (to maintain saturated conditions) will increase the severity of the test, if anything."

During its discussion of LOCA and MSLB environmental profiles, Reg Guide 1.89 states:

"For example, superheated steam followed by saturated steam may be a limiting condition and should be considered."

What test considerations are relevant for chemical spray?

Reg Guide 1.89 states:

"Chemical spray or demineralized water spray that is representative of service conditions should be incorporated during simulated event testing at pressure and temperature conditions that would occur when the spray systems actuate.

For additional discussion regarding this issue, see the following three references:

1. Franklin's generic Technical Evaluation Report, p 52

2. Wyle's report discussing chemical spray differences and their effects on materials.

3. A very recent Japanese report that suggests that insulation and jacket materials such as EPR, HYPALON, and NEOPRENE undergo more dimensional swelling in a water environment than in a chemical spray environment. (JAERI-M-83-072)

Must submergence be considered in the accident simulation?

If the equipment is subject to being submerged, then it must be considered according to 10 CFR 50.49. Note, that submergence is more than submergence integrity to a water environment. The environment may be borated water with the additonal presence of radionuclides.

Is the steam ramp time important?

This issue should be addressed via a failure modes and effects analysis.

We have considered numerous environmental issues relating to equipment qualification. Let us review those issues by listing some questions that may help focus an inspection effort.

INSPECTION QUESTIONS

Environments:

Was a plant specific environmental specification employed for the qualification program? Did the specification include temperature, pressure, humidity, chemical effects, radiation, aging, and submergence? Is the location of the equipment located above or below a flood level? Is the equipment, including all connections, shielded from beta radiation? Is beta radiation shielding based on metallic or polymeric shielding materials (polymeric materials may not survive the total beta dose postulated for a LOCA). Were accident conditions specified for MSLB or HELP accidents as well as LOCA conditions? Were qualification tests based on generic profiles (such as the Appendix A profile of IEEE Std. 323-1974) rather than plant-specific profiles? If so, was a plant specific analysis performed to demonstrate applicability of the generic profile test results? Were process gases and fluids that contact the device or pass through the device specified?

Margins:

Was margin added to the plant specific environmental specification during development of qualification test strategy? Did test acceptance criteria insure that equipment operability was demonstrated for a minimum of at least one hour? If not, was substantial justification provided consistent with Reg Guide 1.89 guidance? Compare test plan margin factors with IEEE Std 323-1974 recommendations. Are differences clearly justified?

Test Simplifications:

Was the same piece of equipment used throughout the environmental qualification effort? Were equipment subcomponents replaced during the aging simulation to account for routine maintenance activities? If so, were maintenance requirements clearly defined by the qualification documentation? Were equipment subcomponents replaced during testing because of random failures? If so, was the replacement subcomponent properly preconditioned? Are preconditioning auditable records available for the replacement component? Was a thorough failure analysis performed to insure that the failure was random? Was a single component being tested when the "random" failure occurred?

Were acceptance criteria specified for before, after and periodically during environmental accident exposures?

Does the qualification documentation include a parts list and a drawing of the device? Check that all non-metallic components of the device are identified in the aging analysis. Was a failure modes and analysis performed to identify those components necessary for the safety-related function. Were all these components considered in the aging analysis? Were self-heating effects accounted for in the aging analysis? Check the maximum rated temperature for each component and insure that the aging temperature employed during accelerated aging is not higher than this temperature without justification. Check the normal operating temperature given for the device. Is it consistent with process fluids or other environments in contact with the device?

Check a few random activation energy references. Are the dgradation mechanisms for the components similar to those measured during the activation energy analysis? Does supporting data indicate that the measured activation energy is independent of temperature or was there a strong temperature dependence? If a temperature dependence occurred, were the high or low temperature regimes used to determine the activation energy? When literature references are employed as a basis for estimating generic activation energies, is a list of literature references supplied. From the range of possibile values was the lowest value chosen as a basis for qualification? Does a test laboratory or manufacturer consistently employ the same literature reference for the same generic material? When analysis is employed to argue component similarity (and hence qualification by similarity), did the analysis consider component lifetime as well as component activation energy?

Verify the aging calcu ation by checking the mathematics. Make sure the intended qualified life is clearly stated and is consistent with stated maintenance requirements.

Does failure modes and analysis suggest that unaged electical modules might be more susceptible to LOCA environments than aged modules?

Were thermal and radiation aging performed in an air environment? Was radiation aging performed at a dose rate greater than 1 Mrd/h. Was applicable published literature regarding dose rate effects, synergistic effects, sequencing effects, and the importance of oxygen evaluated in the test plan? (See Table 13 of the text for a partial list of published literature.)

Were beta doses accounted for via shielding or gamma equivalent test exposures? If shielding was employed, was the shielding installed at all important locations including at interfaces? For example, is there shielding between the cable conduit and the instrument housing? Is the shielding sufficient. Were calculations performed to demonstrate its sufficiency. Were beta heating effects analyzed. Was plant-specific analysis used to justify any reductions in dose or dose rate resulting from component location or shielding? If gamma equivalent test exposures were employed to account for beta radiation, is there a one-to-one correspodence between the test gamma dose and the combined gamma and beta dose requirement?

Were post-accident acceleration techniques employed? Was a conservative activation energy employed? Was a four month functionability requirement satisfied with less than a 15 day test exposre. Was a one year specification satisfied with less than a 29 day exposure? Did post-test acceleration techniques artifically mask potential failure modes for the Class 1E device. For example, was all oxygen removed from the test chamber because saturated steam conditions were employed? Is the Class 1E device subject to moisture intrusion failure modes. Werè temperature, humidity cycling techniques employed as part of the post-accident acceleration process? Were momentary failure modes that depend on temperature or pressure considered prior to post accident acceleration?

Was functionability under MSLB conditions demonstrated by a steam test?

Was mechanical cycling included in the qualification test strategy?

For electrical instrumentation, were the effects of high dose rates at the start of the accident considered in the qualification documentation?

What were the chemical spray conditions employed during testing? Was analysis provided to justify differences between achieved spray conditions and specified conditions. Did the analysis consider the increase in reactivity of the spray solution with temperature? Did the analysis account for the effects of solid chemical deposition on equipment internals, e.g., plateout of salts on terminal blocks internal to motorized valve actuators. Did the analysis reference specific supplemental test data ? Were differences between specified service installation and test conditions for mounting, electrical termination, compartment sealing, cable penetration, and enclosure type analyzed with respect to chemical spray effects?

Were failures to achieve steam ramp times analyzed by a failure modes and effects analysis?

FACILITIES AND INSTRUMENTATION

FOR

QUALIFICATION TESTS

QUALIFICATION TESTS CANNOT BE CONDUCTED WITHOUT FACILITIES THAT ARE CAPABLE OF ACHIEVING THE SPECIFIED TEST CONDITIONS.

1. TEMPERATURES
2. PRESSURES
3. STEAM/HUMIDITY CONDITIONS
4. RAMP TIMES
5. CHEMICAL SPRAYS
6. DOSE RATES

DATA SAMPLING RATES ARE DEPENDENT ON THE SPECIFIC FACILITY.

1. TEST EQUIPMENT SHOULD BE CALIBRATED TO SPECIFIC PERFORMANCE

2. SAMPLING RATES SHOULD BE BASED ON RELIABILITY (PREDICTABILITY) OF EQUIPMENT

3. REQUIRED ACCURACIES SHOULD BE SPECIFIED IN TEST PLAN/PROCEDURE

(IT IS ASSUMED THAT EQUIPMENT HAS CURRENT CALIBRATION).

SIMPLE EXAMPLE DEMONSTRATES REASONABLE JUDGMENT ON SAMPLE RATES.

	THERMAL AGING OVEN		
	A	B	C
THERMOSTAT DEAD BAND	± 2°F	± 2°F	± 5°F
EXPECTED DRIFT	± 1°F/MONTH	± 5°F/MONTH	± 1°F/MONTH
DATA SAMPLE RATE	2 TIMES/DAY	10 TIMES/DAY	CONTINUOUS

OFTEN A STRIP CHART RECORDER IS USED FOR ALL CASES--
PROVIDES CONTINUOUS (ANALOG) DATA.

THE RADIATION EXPOSURE IS OFTEN DONE BY A SUBCONTRACT FACILITY (I.E., ISOMEDIX).

1. OFTEN HAVE TO RELY ON CERTIFICATION FROM SUBCONTRACTOR
2. CHECK DOSE RATE X EXPOSURE TIME = TID
3. COMPARE DOSE RATES AND TID'S WITH TEST PLAN
4. WAS SPECIMEN ROTATED TO RECEIVE A MORE EVEN DOSE

YOU DON'T HAVE TO BE AN EXPERT TO INSPECT DOSIMETRY TECHNIQUES!

1. ALL CALIBRATIONS SHOULD BE TRACEABLE TO NBS.

2. THERE SHOULD BE PROCEDURES FOR ENSURING THAT ALL INSTRUMENTS IN A SYSTEM ARE WORKING.

TEMPERATURE OF SPECIMEN SHOULD BE MONITORED DURING RADIATION EXPOSURE.

1. TO MONITOR RADIATIVE HEATING FROM SOURCE

2. PREFERABLY USE THERMOCOUPLE MOUNTED TO SPECIMEN

3. MONITORING TEMPERATURE OF OTHER OBJECT NOT USUALLY SUFFICIENT

LOCA SIMULATIONS ARE MUCH MORE COMPLICATED THAN THERMAL AGING OR RADIATION EXPOSURES.

1. TRANSIENT PRESSURES/TEMPERATURES

2. SATURATED VERSUS SUPERHEATED STEAM

3. CHEMICAL SPRAY

4. TEST SPECIMEN OPERATION AND MONITORING

SPECIAL CONSIDERATIONS FOR INSTRUMENTS MEASURING TRANSIENTS PHENOMENA.

1. RANGE

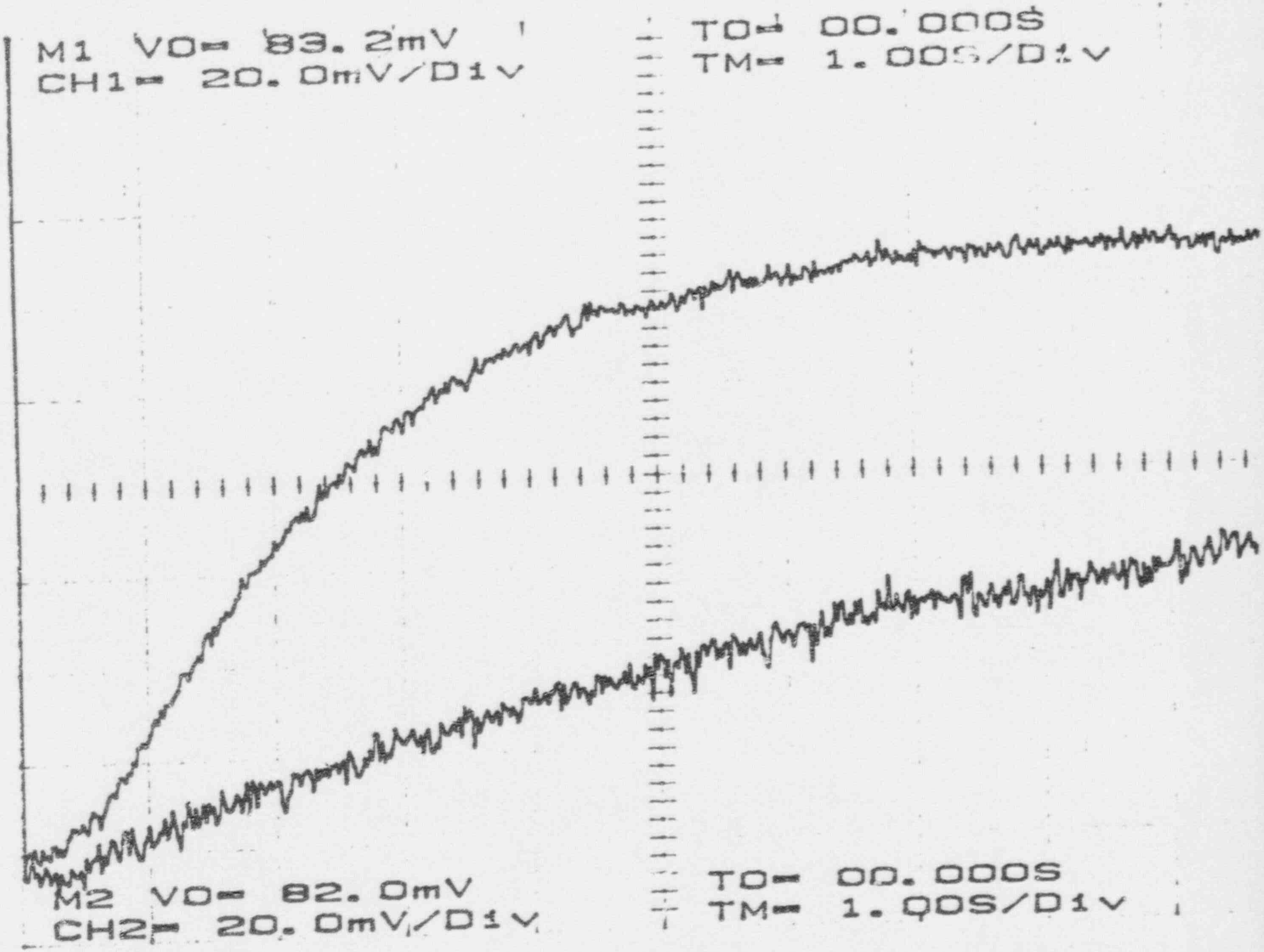
   A) SENSOR

   B) RECORDER

2. RESPONSE TIME

3. CONDENSATION

4. DATA SAMPLING RATE


M1 VO= 83.2mV
CH1= 20.0mV/DIV
TO= 00.000S
TM= 1.00S/DIV
M2 VO= 82.0mV
CH2= 20.0mV/DIV
TO= 00.000S
TM= 1.00S/DIV

SATURATED/SUPERHEATED STEAM CONDITIONS MUST BE 'CALCULATED' RATHER THAN MEASURED DIRECTLY.

1. FEW OR NO RELIABLE METHODS TO "MEASURE" RELATIVE HUMIDITY ABOVE 95%.

2. IMPORTANT TO DISTINGUISH BETWEEN SATURATED AND SUPERHEATED STEAM BECAUSE

   A) SUPERHEAT CONDITIONS DRY OUT POLYMERS (SEALS, ETC.)

   B) SATURATED CONDITIONS PROVIDE MOISTURE TO FAIL ELECTRICAL SYSTEMS

SUPERHEATED STEAM CONDITIONS ARE ASSURED BY MEASURING TEMPERATURE AND PRESSURE AND USING STEAM TABLES.

SATURATED STEAM TABLES

TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE
200°F	11.529 PSI	290°F	57.53 PSI	390°F	220.2 PSI
210	14.125	300	66.98	400	247.1
212	14.698	310	77.64	410	276.5
220	17.188	320	89.60	420	308.5
230	20.78	330	103.00	430	343.3
240	24.97	340	117.93	440	381.2
250	29.82	350	134.53	450	422.1
260	35.42	360	152.92	460	466.3
270	41.85	370	173.23		
280	49.18	380	195.60		

POSSIBLE ERROR EXISTS IN CALCULATING SATURATED STEAM CONDITION.

1. HOW MUCH AIR IS LEFT IN CHAMBER WHEN STEAM IS ADDED?

2. MUST OVERPRESSURES BE EMPLOYED IF OXYGEN IS REQUIRED?

3. APPENDIX C OF IEEE 323-1974 GIVES METHOD FOR ASSURING SATURATED CONDITIONS.

APPENDIX C SHOWS THAT SATURATED STEAM CONDITIONS ARE DIFFICULT TO ENSURE WITH CALCULATIONS ALONE.

1. AMOUNT OF AIR IN TEST CHAMBER IS NOT KNOWN.

2. MIXTURE OF AIR AND STEAM AT TEMPERATURE T AND PRESSURE P.

3. P = SUM OF PARTIAL PRESSURES = $P_A + P_S$.

4. $T = T_S = T_A$.

5. AT 100% RELATIVE HUMIDITY, P_S MUST EQUAL P_{SAT} AT T.

6. BUT NO WAY TO MEASURE P_{SAT}.

AN ALTERNATIVE METHOD FOR ASSURING SATURATED STEAM CONDITIONS IS GIVEN IN APPENDIX C OF IEEE 323.

1. SATURATED CONDITIONS WILL EXIST IF THERE IS THERMAL EQUILIBRIUM BETWEEN WATER VAPOR AND LIQUID WATER.

2. SO, USE CONTAINER OF WATER AT SAME TEMPERATURE AS GAS.

3. MUST BE ABLE TO EVAPORATE WATER QUICKLY.

4. KEEP WATER BOILING.

5. CHAMBER ATMOSPHERE MUST BE STUDIED.

6. MAY SPARGE STEAM THROUGH WATER.

SSINS NO: 6835
IN 84-44

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
WASHINGTON, D.C. 20555

June 8, 1984

IE INFORMATION NOTICE NO 84-44: ENVIRONMENTAL QUALIFICATION TESTING OF ROCKBESTOS CABLES

Addressees:

All holders of a nuclear power reactor operating license (OL) or construction permit (CP).

Purpose:

This information notice is provided to inform licensees and construction permit holders of potential generic problems regarding Rockbestos environmental qualification (EQ) testing of Class 1E electrical cables. Addressees are expected to review the information for applicability to their facilities. No specific action or response is required.

Description of Circumstances:

The NRC has performed a number of inspections of the QA programs established at several environmental testing facilities. This effort was started in late August 1982 to assess the facilities' establishment and implementation of a QA program based on the requirements of 10 CFR Part 50, Appendix B. Several such inspections were recently conducted at the Rockbestos Company in New Haven, Connecticut. The NRC inspection team reviewed qualification related documents such as EQ reports, associated supporting items including test plans, test procedures, test instruments, test log books, related raw data and QA documents. The inspections revealed several QA nonconformances and related testing/documentation problems. Details of these nonconformances and inspection findings are documented in the following NRC Inspection Reports: 99900277/83-01, 99900277/83-02, and 99900277/83-04. Listed below are some of the QA nonconformances and related testing/documentation problems which may affect the qualification of Rockbestos cables that are installed at licensees' facilities:

1. The Rockbestos Company did not impose quality assurance/test control requirements on an outside test organization which performed testing (LOCA/HELB) during the period of 1969-1979.

2. The Rockbestos Company did not establish and implement a QA program in accordance with 10 CFR Part 50, Appendix B requirements to control Rockbestos EQ testing; i.e., the EQ program was controlled by a Rockbestos engineering organization which was not under a QA program until 1983.

3. As a result of inadequate QA controls, testing and the required documentation were not properly controlled. Several discrepancies between final qualification reports and supporting test data were found.

4. Rockbestos' QA and engineering organizations did not impose QA and technical requirements/acceptance criteria on organizations that performed qualification testing for Rockbestos between 1969 and 1979. Furthermore, no supporting test data for these tests were available for audit at Rockbestos or subtier test organizations.

5. Test equipment and instrumentation were observed to have inadequate resolution to record LOCA test parameters and functioning of test specimen during testing.

6. Test equipment was not properly calibrated or under the control of the calibration system. An internal Rockbestos audit dated May 10, 1983, documented these generic deficiencies in their calibration system.

7. Test plans, acceptance criteria, and test procedures for certain qualification tests were not made available during the NRC audits.

8. A number of test deficiencies, deviations, and other anomalies were not documented and evaluated in the test reports.

Discussion:

The results of the NRC inspections show that several deficiencies were present in the Rockbestos Company qualification programs in effect at time of the audit. Individually, some deficiencies could be adequately reconciled, but taken collectively, the nature and number of deficiencies identified would not adequately demonstrate that acceptable qualification had been established. It appears that the validity of some of the Rockbestos qualification reports is in doubt, however, the NRC staff has concluded at this time that no immediate safety problem exists in the use of Rockbestos cables. The NRC staff considers that it is the responsibility of the user utilities to review the information provided above and take applicable corrective action to ensure the qualification of Rockbestos cables installed in their plants. The following possible courses of corrective action should be considered:

a) Perform a valid qualification test of the installed Rockbestos cables.

b) Obtain documentation from other available qualification tests already performed and determine its applicability to the installed cables.

c) Perform analyses of existing qualification reports applicable to the installed cables to ensure that the documentation relied upon to demonstrate environmental qualification supports such a conclusion.

The NRC staff considers this review to be part of the on-going activities that the licensees are currently undertaking to resolve other environmental qualification deficiencies to meet the deadline and requirements set forth in the EQ final rule, 10 CFR 50.49.

Questions regarding details of, and resolutions to the NRC inspection findings described above should be directed either to the equipment manufacturer, or the cognizant design/test agency. If you have questions regarding this information notice, contact the Regional Administrator of the appropriate NRC Regional Office, or this office.

Edward L. Jordan, Director
Division of Emergency Preparedness
and Engineering Response
Office of Inspection and Enforcement

Technical Contacts: R. G. LaGrange, NRR
(301) 492-8208

N. B. Le, IE
(301) 492-9673

Attachment:
List of Recently Issued IE Information Notices

TODAY'S PRESENTATION IS INTENDED TO BE A GENERAL REVIEW OF TEST FACILITIES AND INSTRUMENTATION.

1. REVIEW THE APPLICABLE REQUIREMENTS

2. DISCUSS FACILITIES AND INSTRUMENTATION FOR THE DIFFERENT PHASES OF A QUALIFICATION TEST

3. DISCUSS EXAMPLE FROM ROCKBESTOS INSPECTION

(TOUR ON FRIDAY WILL INCLUDE MORE INFORMATION ON TEST FACILITIES AND INSTRUMENTATION)

IEEE 323-1974 SPECIFIED GENERAL MONITORING REQUIREMENTS IN SECTION 6.3.1.4.

"THE TEST SHALL BE MONITORED USING EQUIPMENT THAT PROVIDES RESOLUTION FOR DETECTING MEANINGFUL CHANGES IN THE VARIABLES. THE TEST EQUIPMENT SHALL BE CALIBRATED AGAINST AUDITABLE CALIBRATION STANDARDS AND SHALL HAVE DOCUMENTATION TO SUPPORT SUCH CALIBRATION. THE TIME INTERVAL BETWEEN MEASUREMENTS SHALL BE SUCH AS TO OBTAIN THE TIME DEPENDENCE OF EACH VARIABLE."

IEEE 323-1974 CLASSIFIED THE MEASURED VARIABLES INTO GENERAL CATEGORIES.

1. ENVIRONMENT. TEMPERATURE, PRESSURE, MOISTURE CONTENT, GAS COMPOSITION, VIBRATION, AND TIME.

2. INPUT ELECTRICAL CHARACTERISTICS. FREQUENCY, CURRENT, VOLTAGE, POWER TO THE EQUIPMENT, AND TIME DURATION OF THE INPUT.

3. FLUID CHARACTERISTICS. CONCENTRATION OF CHEMICAL CONSTITUENTS IN FLUID INJECTED INTO THE TEST CHAMBER PLUS THE FLOW RATE AND SPRAY DISPOSITION AND TEMPERATURE OF SUCH FLUIDS.

Steve Alexander

IEEE 323-1974 CLASSIFIED THE MEASURED VARIABLES INTO GENERAL CATEGORIES.

4. RADIOLOGICAL FEATURES. NUCLEAR RADIATION DATA INCLUDING ENERGY TYPE, ENERGY LEVEL, EXPOSURE RATE, AND INTEGRATED DOSE.

5. ELECTRICAL CHARACTERISTICS. INSULATION RESISTANCE OF ELECTRICAL COMPONENTS; VOLTAGE, CURRENT, AND POWER OUTPUT; RESPONSE TIME; FREQUENCY CHARACTERISTICS; AND SIMULATED LOAD.

IEEE 323-1974 CLASSIFIED THE MEASURED VARIABLES INTO GENERAL CATEGORIES.

6. MECHANICAL CHARACTERISTICS. THRUST, TORQUE, TIME, AND LOAD PROFILE.

7. AUXILIARY FUNCTION MEASUREMENTS. FUNCTION MEASUREMENTS RELATED TO CLASS 1E EQUIPMENT WHICH ARE INCLUDED IN THE EQUIPMENT BUT NOT NECESSARILY FOR ITS OWN OPERATION; THAT IS ITEMS WHICH ARE REQUIRED TO PROVIDE A SIGNAL TO CONTROL OTHER CLASS 1E EQUIPMENT (I.E., AUXILIARY SWITCHES AND POSITION FEEDBACK POTENTIOMETERS).

FACILITY AND INSTRUMENTATION REQUIREMENTS ARE DIFFERENT FOR THE THREE PHASES OF AN ENVIRONMENTAL QUALIFICATION TEST.

1. THERMAL AGING

2. RADIATION EXPOSURES

3. LOCA SIMULATION

THERMAL AGING IS THE PROCESS OF MAINTAINING A COMPONENT AT A SPECIFIED TEMPERATURE FOR A SPECIFIED TIME.

1. TEMPERATURE AND TIME ARE CALCULATED FROM AN AGING ANALYSIS.

2. STEADY-STATE PROCESS.

3. REQUIRES TEST CHAMBER OR OVEN WITH

   A) ACCURATELY CONTROLLED TEMPERATURES (I.E., $\pm$ 2°F)
   B) UNIFORM ENVIRONMENT
   C) MAY OR MAY NOT REQUIRE SPECIAL ATMOSPHERE (USUALLY) OR HUMIDITY CONTROLS

UNIFORM ENVIRONMENT IS IMPORTANT IN THERMAL AGING.

1. NO SPECIFIC VOLUME REQUIREMENTS FOR CHAMBER

2. ATMOSPHERE CIRCULATION

3. SHOULD HAVE "ENOUGH" THERMOCOUPLES TO DEMONSTRATE UNIFORMITY

4. THERMOCOUPLES SHOULD BE SHIELDED FROM ANY RADIATIVE HEAT SOURCES (LIKE HEATING COILS)

AGAIN, THE IMPORTANT THING IS TO DEMONSTRATE THAT THE TEST CONDITIONS WERE MET--NOT CRUCIAL HOW THEY WERE ACHIEVED.

WITHOUT ADEQUATE INSTRUMENTATION, QUALIFICATION IS MEANINGLESS.

1. IF THE INSTRUMENTATION IS INSUFFICIENT, IT DOESN'T MATTER HOW GOOD THE FACILITY IS, OR HOW WELL THE EQUIPMENT PERFORMS.

2. INSTRUMENTATION IS THE LINK BETWEEN THE ACTUAL PERFORMANCE OF THE EQUIPMENT AND THE QUALIFICATION OF THE EQUIPMENT.

3. Calibration of the instruments

TEST INSTRUMENTATION HAS SEVERAL FUNCTIONS.

1. TO MONITOR TEST CONDITIONS

2. TO MONITOR EQUIPMENT PERFORMANCE BEFORE, DURING AND AFTER TEST

3. TO PROVIDE A RECORD (DOCUMENTATION) OF THE TEST

ACCEPTANCE CRITERIA

Background

Acceptance criteria provide the basis for deciding if equipment passes or fails a qualification test. In order for a qualification effort to be meaningful, acceptance criteria must be specified. Acceptance criteria define the level of performance at which the equipment is required to function for a given environment. For example, an RTD (resistance temperature detector) may be required to measure temperature within ± 2 F during a LOCA. It is possible that the RTD may survive the LOCA environment (i.e. still give a temperature reading) but is not within the specified tolerance of ± 2 F. Thus the acceptance criteria would not be met, and the RTD would have failed the test. This simple example points out the importance of choosing acceptance criteria carefully so that they are appropriate for the intended application of the equipment. Often, however, acceptance criteria are either not clearly specified or are chosen somewhat arbitrarily. Enter, the inspection.

Requirements

IEEE 323-1974 is fairly specific regarding acceptance criteria:

Section 6.2, "Equipment Performance Specifications," states "Electric equipment specifications shall define the equipment's Class 1E requirements and shall include as applicable:

1. Performance characteristics under defined normal, abnormal, containment test, design basis event, and post design basis event conditions
2. The range of voltage, frequency, load, electromagnetic interference, and other electrical characteristics
3. The installation requirements including mounting method and configuration(s)
4. Preventive maintenance schedule for the installed life of the equipment, (including lubricants and seals)
5. The design life of the equipment and the design life of any components which may have a life shorter than that of the complete equipment
6. Control, indicating, and other auxiliary devices contained in the equipment or external to the equipment and required for proper operation
7. The range, type, and duration of environmental conditions including temperature, pressure, humidity, radiation, chemicals, and seismic forces
8. Complete description and number of operating cycles including periodic testing
9. Qualified life. (This Performance Specification entry may be established during the qualification testing)"

Section 6.3.1.1 states, in part, "The test plan should contain.... performance limits or failure definition."

Section 6.5.4, "Determination of Qualification," states " The electric equipment type shall be considered to be qualified by demonstrating that the equipment performance will meet or exceed its specified values for the most severe environment or sequence of environments in the equipment specification during its qualified life."

Section 6.7, "Criteria of Failure," states "In the evaluation of thee qualification test results, any sample equipment is considered to have failed when the equipment does not perform the Class 1E functions required by the equipment specifications."

There are similar statements in other documents, such as 10CFR50.49, section (d): ".....the applicant or licensee shall include the following information for this electric equipment important to safety in a qualification file:

1. the performance specifications under conditions existing during and following design basis accidents.

2. The voltage, frequency, load, and other electrical characteristics for which the performance specified in accordance with paragraph (d)(1) of this section can be ensured.

3. The environmental conditions, including temperature, pressure, humidity, radiation, chemicals, and submergence at the location where the equipment must perform as specified in accordance with paragraphs (d)(1) and (2) of this section."

The requirements for acceptance criteria are relatively specific, but they are not detailed enough to be applied directly to a qualification file during an inspection.

Inspecting Acceptance Criteria

There are several things to consider when inspecting acceptance criteria. First is whether or not any are included in the qualification package at all. Given that there are, one must then check them to see if they are consistant with the appropriate purchase order (for a test lab) or other applicable specifications (such as FSAR for a plant). Once this internal consistancy is established, one may proceed to assess the technical adequacy of the acceptance criteria themselves.

To do this, it is necessary to have an understanding of the intended safety function of the equipment. For example, in the case of a cable, is it in a power circuit, control circuit, or instrumentation circuit? Each of these require different acceptance criteria. Instrumentation circuits have much lower current loads and are much more sensitive to noise, while power circuits will likely have high current loads and may be suseptible to resistive heating. Thus the performance requirements for different applications of similar equipment may be quite different.

A good way to inspect acceptance criteria is to use past findings and experience (from both the NRC and industry) as a guide. The best way to illustrate this is with an example from some Sandia research on terminal blocks. (See paper by C. M. Craft.)

Acceptance Criteria

- Acceptance criteria provide the basis for deciding whether equipment passes or fails a qualification test.

- Acceptance criteria define the level of performance at which the equipment is required to function for a given environment

Equipment may still "work" during and after test, but still fail the qualification test.

Example

Test: qualification of RTD for LOCA environment

Acceptance criteria: RTD must maintain accuracy of ± 4°F before, during, and after test

Result: RTD accuracy was within tolerance before and after test, but was out of spec for a few minutes during LOCA exposure

Qualification status: not qualified

IEEE 323-1974 is relatively specific regarding acceptance criteria

Section 6.2 states "Electric equipment specifications shall define the equipment's Class 1E requirements"

Section 6.3.1.1 states, in part, "The plan should contain . . . performance limits or failure definition"

Section 6.5.4, "Determination of Qualification," states "The electric equipment type shall be considered to be qualified by demonstrating that the equipment performance will meet or exceed its specified values for the most severe environment or sequence of environments in the equipment specification during its qualified life."

Section 6.7, "Criteria of Failure," states "In the evaluation of the qualification test results, any sample equipment is considered to have failed when the equipment does not perform the Class 1E functions required by the equipment specifications."

Acceptance criteria encompass all aspects of equipment performance

1. Performance characteristics under defined normal, abnormal, containment test, design basis event, and post design basis event conditions.

2. The range of voltage, frequency, load, electromagnetic interference, and other electrical characteristics

3. The installation requirements including mounting method and configuration (s)

4. Preventive maintenance schedule for the installed life of the equipment (including lubricants and seals)

5. The design life of the equipment and the design life of any components which may have a life shorter than that of the complete equipment

6. Control, indicating, and other auxiliary devices contained in the equipment or external to the equipment and required for proper operation.

7. The range, type, and duration of environmental conditions including temperature, pressure, humidity, radiation, chemicals, and seismic forces

8. Complete description and number of operating cycles including periodic testing

9. Qualified life. (This Performance Specification entry may be established during the qualification testing)

10CFR50.49 contains similar requirements applicable to licensee's qualification files

The files must contain

1. the performance specifications under conditions existing during and following design basis accidents.

2. The voltage, frequency, load, and other electrical characteristics for which the performance specified in accordance with paragraph (d) (1) of this section can be ensured.

3. The environmental conditions, including temperature, pressure, humidity, radiation, chemicals, and submergence at the location where the equipment must perform as specified in accordance with paragraphs (d) (1) and (2) of this section.

Although the requirements for acceptance criteria are relatively specific, they do not contain enough details to be applied directly to a qualification file during an inspection.

Acceptance Criteria can be inspected by asking a series of questions

1. Are they addressed in the qualification file?

   No - obvious non-conformance

   Yes - proceed to Question 2

2. Are the acceptance criteria consistent with the appropriate purchase order or FSAR specifications?

No - non-conformance against IEEE 323-1974 Section 6.5.4 "Determination of Qualification"

Yes - proceed to Question 3

3. Are the acceptance criteria technically adequate?

To answer this question, it is necessary to have an understanding of the intended safety function of the equipment

Example - Qualification of Cable

Power Circuits and Instrumentation circuits should have different acceptance criteria.

Power circuits have high current loads and may be susceptible to resistive heating

acceptance criteria: thermal properties of insulation

Instrumentation circuits have low current loads and are sensitive to noise

acceptance criteria: adequate shielding

Past findings and experience, from both industry and NRC, can be used as a guide to inspecting acceptance criteria

Common Mode

vs.

Random Failures

Random failures are the result of random variations in material and component properties and manufacturing processes

1. independent of wearout

2. not expected to occur simultaneously

3. taken care of by surveillance and maintenance

Common mode failures are failures due

to a common mechanism or cause

1. "mechanism" is the basic physical cause of failure, such as corrosion or wear

2. "mode" is method of failure, such as the opening of a circuit due to corrosion or the seizure of a bearing due to wear

3. common mode failures may also occur as a result of a design flaw or error in manufacturing process

4. these are the failures that are of concern when qualifying equipment

If a component fails a qualification test, it is necessary to determine whether the failure was random or common mode.

1. not easy without statistical tests
2. must use analysis and judgement
3. should monitor safety-system equipment that had a random-failure during qualification.

Vol. 5

Performance and Effects of Terminal Blocks in a Loss of Coolant Accident Environment*

Charles M. Craft
Sandia National Laboratories
Albuquerque, New Mexico

Abstract

Terminal blocks continue to be used in instrumentation and control (I&C) applications in the nuclear power industry. However, for many terminal blocks the qualification tests use an acceptance criterion which does not quantify the performance of terminal blocks at the low voltage and current levels of I&C applications. Our tests monitored terminal block performance during LOCA steam and chemical spray simulations and were conducted at current and voltage levels representative of I&C applications. Leakage currents from 0.5 mA to 15 mA were observed. These values are of sufficient magnitude to affect some I&C applications.

1.0 Applications of Terminal Blocks in the Nuclear Industry

Historically, terminal blocks have been used by the nuclear industry to make cable junctions in both Class 1E and non-Class 1E circuits inside and outside containment. Applications range from low voltage instrumentation circuits to 480 Vac power circuits, with most of the applications in the low power instrumentation and control circuits. A review of industry's equipment qualification submittals and a survey of industry representatives (Ref. 1) provides a picture of terminal block usage in the nuclear industry. Table 1 summarizes some of the pertinent results from that reference. All of the terminal blocks listed are used in both inside and outside containment applications. Approximately 60 percent of the utilities are planning to continue using terminal blocks in Class 1E circuits inside containment. Those choosing to use terminal blocks in these applications operate mostly older plants with a large number of installed terminal blocks, but some of the newer plants will also use terminal blocks. Alternately, some utilities have removed all explicit** terminal blocks in Class 1E applications inside containment (e.g., Duke Power); and others are removing them from selected applications (e.g., transmitter circuits) or locations (e.g., below submergence level). The major trend for new plants is to use splices inside containment. The two major designs of terminal blocks (one piece and sectional) are in approximately equal usage. Reference 1 tabulates 57 distinct models of terminal blocks, 32 are of sectional construction and 25 are of one-piece construction. However, one-piece terminal blocks are probably more numerous in absolute terms since they are specified by a larger number of plants. To characterize terminal block types by a percentage of total population is difficult, since data for the numbers of each type as well as the total population of terminal blocks are not readily available. Some of the utilities would also have difficulty in identifying the number of each type of terminal block in their plants, and to do so would probably require a walkdown of the plant.

---

*This work supported by the United States Nuclear Regulatory Commission and performed at Sandia National Laboratories which is operated for the U.S. Department of Energy Under Contract Number DE-AC04-76DP00789.

**The term explicit refers to terminal blocks which are not integral parts of larger pieces of equipment such as electrical penetrations or motor operators.

Table 1
Summary of Terminal Block Usage in the
US Nuclear Power Industry

Manufacturer	Model	Number of Plants Using*	Percent of Plants Operating**	Percent of Plants All**
General Electric	EB Series	33	43	23
	EB-25	25	32	17
	EB-5	23	30	16
	CR151 Series	14	18	10
Weidmuller	SAK Series	18	23	12
Westinghouse	542247,805432	11	14	8
States	Type NT	10	13	6
	Type ZWM	6	8	4
Buchannan	NQB Series	8	10	6

NOTE: Forty-one different model numbers are each used in 4 or fewer plants

* Based on data from 73 of 77 operating plants and 17 of 68 planned or under construction plants.

** Based on world list of nuclear power plants in the August 1983 Issue of Nuclear News. Seventy-seven operating plants (including TMI-2) and 68 planned or under construction plants, for a total of 145 nuclear plants in the US.

2.0 Industry Qualification of Terminal Blocks

Since 1977, there have been a number of test programs sponsored by both utilities and terminal block manufacturers that have been used to support qualification of terminal blocks (Refs. 2 through 8). These tests generally age the terminal blocks using Arrenhius techniques or the 10°C rule, expose the terminal block to a seismic test, and then conduct a LOCA/HELB simulation. Functional tests normally consist of insulation resistance (IR) measurements and conductor continuity checks between each of the sequentially applied environments (i.e., thermal aging, radiation, seismic tests, LOCA simulation.) All industry test reports reviewed by us indicate that the terminal blocks pass the functional IR tests subsequent to each type of exposure. Measurements of the variations in terminal block performance during these tests with the blocks powered is generally not conducted, though about half of the tests depower the blocks and make megohmmeter measurements. The WPPSS test of Weidmuller blocks in a post-LOCA soak environment (Ref. 6) and the Phonix test of their own blocks (Ref. 8) did monitor leakage currents without depowering the blocks. For the other tests the typical method used to monitor terminal block performance during the LOCA/HELB simulation is via fuses in the circuit providing power to the terminal block. These fuses are sized to fail at between 1 A to 24 A of leakage current depending on the test specification. Acceptance criteria are based on whether or not the terminal blocks can maintain the specified voltage and current without failing the fuses. Typically, during a test the fuses to one or more terminal blocks will fail one or two times and be replaced. Sometimes a terminal block is unable to keep the fuses from blowing and that terminal block will be removed from the test. An important point which is not specified is how often a fuse is allowed to fail or how many terminal blocks are allowed to be removed from the test, before the test lot is determined to have failed. Further, using fuses to monitor during-test performance has two drawbacks: first, the failure of a fuse is only a single point criterion that says leakage current was at least as large as the rated value of the fuse for the time necessary to fail the fuse; and second, the sizing of the fuses to "large" values provides no information about low level leakage currents. Low level leakage currents can affect low power, instrumentation and control circuits which are the primary terminal block applications. In this sense, the acceptance criteria are not germane to the majority of terminal block applications. Table 2 provides a brief comparison and summary of some industry terminal block qualification reports.

3.0 Sandia Tests of Terminal Blocks in a Simulated LOCA Environment

Earlier work at Sandia (Ref. 9) consisted of testing terminal blocks under TMI conditions. This test raised questions regarding terminal block performance but was not conclusive in that there were several areas where test conditions deviated from actually installed conditions. Therefore, to quantify the performance of realistically-installed and protected terminal blocks in a LOCA environment and to investigate terminal block failure and degradation modes, we tested 24 terminal blocks (5 models from 4 manufacturers) in a simulated LOCA environment (Ref. 10). Based on our reviews of the qualification documents, we determined that neither the accelerated aging process nor the seismic testing significantly affected terminal block performance. Thus, we tested terminal blocks in the "as received" condition. To simulate normal handling during installation, no special care was taken during test preparation to prevent the deposit of fingerprints or other normal contaminants on the terminal block surfaces; however, we did not simulate deposits of construction dirt or other sediments which tend to accumulate over time. As such, the terminal blocks were probably in the best initial condition that might possibly exist for terminal blocks installed in the field. The terminal blocks were protected by NEMA-4 electrical enclosures with 1/4" diameter weep holes in the bottom. Cables entered the boxes from the side through nuclear grade liquid tight conduit. To simulate cables entering a conduit from a cable tray system, the conduit was terminated inside the test chamber and was unsealed at both ends.

The test was divided into two phases. Phase I consisted of an 11-day exposure to a steam only environment. Phase II consisted of approximately one day of simultaneous steam and chemical spray followed by a 5-day exposure to a steam environment. Both temperature profiles closely followed the PWR temperature profile recommended by IEEE 323-1974, Appendix A (Ref. 11). Saturated steam conditions were maintained throughout both test phases. In Phase I, the terminal blocks were connected in an alternating pole serpentine, similar to the wiring scheme used in industry qualification tests (Figure 1). In Phase II, the terminal blocks were connected in a configuration more representative of actual plant connections with one pole powered and the two adjacent poles and ground plate monitored for leakage currents (Figure 2). One terminal block in the Phase II test was connected to a pressure transmitter in a circuit configuration representative of a plant transmitter circuit. This transmitter circuit was included to validate the results obtained from the other circuits and to confirm the analysis of the effects of terminal block degradation on low power circuits. Figure 3 shows the transmitter circuit wiring.

Table 2
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohm Meter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
Philadelphia Electric/ FRC*	Buchannan 2B104 2B108	 4 2	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$< 5x10^4$ at 50 Vdc	10^2 to 10^{12}	One block removed from test at 4.9 days. Others removed at various times.	14 d	2 Phase A
Philadelphia Electric/ FRC*	Buchannan 2B108 Marathon 1608	 3 2	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$< 5x10^5$ at 50 Vdc	$< 5x10^4$ at 50 Vdc to $< 5x10^5$ at 50 Vdc	One TB removed from from test after 5.1 hours.	7d	2 Phase B
Generic/ FRC*	Weidmuller SAK Types	5	Maintain 600 Vac and 20 A with leakage current less than 1 A. Monitored by fuse.	600 Vac 20 A	None	$2.4x10^7$ to $3.5x10^8$ at 500 Vdc	Voltage reduced to 150 V when spray introduced to maintain leakage current less than 1 A.	29 hr	3
Generic/ FRC*	Buchannan NQB106 NQB112 NQB106S NQB112S NQO Series	 1 1 1 1 1	Maintain potential of 120 V and current of 25 A.	120 Vac 25 A	$< 5x10^4$ at 10 V to $2x10^{12}$ at 500 V	Post-test hipot test	During LOCA, leakage currents were < 200 mA to < 5 mA for all terminal blocks together.	7 d	4
Generic/ Wyle (Huntsville)	Marathon 1600 NUC 1500 NUC 142 NUC	 6 6 6	Leakage currents less than 12 A, or 18 A, or 24 A. Monitored by fuse.	132 Vac, 33 A 264 Vac, 33 A 528 Vac, 33 A	None	$< 5x10^5$ for all 528 V boxes	Blew 25 A fuse on 528 Vac specimens. Removed from test. Blew 18 A fuse on 264 Vac specimens. Replaced fuse and continued.	30 d	5

*FRC = Franklin Research Center

Table 2 (cont)
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility, Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohm Meter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
WPPSS/Wyle (Norco)	Weidmuller SAK Types (same TBs as tested by Weidmuller, Ref. 3)	5	1 A Leakage current Monitored by fuse and discrete time monitoring of leakage currents.	600 Vac 20 A	None	$1.2x10^5$ to $5.0x10^{10}$	Measured leakage current during test. Test was only a post-test LOCA soak. 230°F and 20 psig, 100% relative humidity. No steam.	32 d	6
Generic/ Acton	States ZWM Types	(REPORT NOT AVAILABLE TO US)							7
Generic/ Wyle (Norco)	Phonix SSK Series Ceramic KEK Series Ceramic SSK Series Melamine A Series Polyester (2 Types)	30 units exposed to LOCA	None specified	420 Vac 20 A 48 Vdc	None Reported		2 superheated steam periods. No leakage current measurements of DC circuits. < 40 mA to > 700 mA current observed in 420 Vac case	24 hr	8

*FRC = Franklin Research Center

The terminal blocks were powered at voltages typical of in-plant applications: 4 Vdc typical of RTD circuits (Phase I only), 45 Vdc typical of instrumentation circuits, and 125 Vdc typical of control circuits. The terminal-to-terminal leakage currents were monitored in both Phase I and Phase II tests, and the terminal-to-ground leakage currents were monitored in the Phase II tests. The data was acquired at discrete time steps by data loggers. The time interval between successive measurements varied depending on the experimental activity being conducted. For example, during steam ramps or other transients, monitoring was accomplished as rapidly as possible (about every 6 seconds); during long periods of steady state conditions, the monitoring interval was lengthened to 30 minutes. Based on this data, insulation resistances were calculated for each leakage path on each terminal block. Four channels of leakage current data were monitored continuously by strip chart recorders throughout the test.

Surface leakage currents through conducting surface moisture films are the primary mechanism by which terminal blocks contribute to instrumentation and control circuit degradation. During our tests, the formation of surface films reduced insulation resistance to 10^2 to 10^5 ohms from initial values of 10^8 to 10^{10} ohms. Figures 4 and 5 illustrate these changes in insulation resistance for both Phase I and II at various LOCA temperature conditions. At 45 Vdc, leakage currents were on the order of 0.1 to 10 mA. These values are sufficiently large to affect 4 to 20 mA instrumentation circuits by 0.2 to 170 percent with a nominal effect of 0.5 to 46 percent at the mid-range of instrument output. At 4 Vdc, insulation resistance was $5x10^3$ to $7x10^4$ ohms, values which are sufficiently low to affect RTD measurements by 0.2 to 8 percent. At 125 Vdc, the IR values were comparable to the 45 Vdc values and were at times slightly (approximately 1/2 to 1 order of magnitude) higher. We experienced one open failure where the leakage currents increased over a 90-minute period to values which caused the 12 AWG wire supplying power to the terminal block to separate and open the circuit. The separation occurred at the terminal block-wire junction.

During the periods of cooldown to 95°C and the post-test ambient temperature period, the insulation resistance values increased to 10^6 to 10^8 ohms but not to the pre-test values of 10^8 to 10^{10} ohms. This behavior illustrates three points: first, the similarity between cooldown and post-test IR values indicates that the same conduction mechanism is probably occurring during these periods; second, IR recovery to higher values after exposure indicates that a transient phenomenon is responsible for the low IR values during the steam exposure; and third, that some permanent degradation of the terminal block insulation resistance occurs. A conductive moisture film is the most probable explanation for the transient phenomenon. During cooldown periods, the residual heat of the terminal block will keep its temperature higher than the surrounding atmospheric temperature. Since the surface film will be close to the terminal block temperature, its vapor pressure will exceed the surrounding atmosphere's pressure, causing the film to vaporize. In the post-test case, the same phenomenon occurs until the terminal blocks cool to ambient temperature. Then the normal relative humidity regime takes over. The permanent degradation of the terminal block IR may have been caused by carbonization of the terminal block surface or other organic materials in the vicinity, or by residues of semiconducting mediums such as cadmium sulfide. Post-test chemical analysis of three Phase II terminal blocks showed the presence of both cadmium sulfide deposits and carbonaceous residues in a graphite-like structure.

There was a noticeable dependence of IR on temperature. The IR's at temperatures less than 110°C tended to be 1/2 to 2 orders of magnitude greater than IR's at temperatures greater than 110°C. The improvement in the 95°C values can be attributed to the vaporization of the moisture film; however, the values at the long 105°C soak periods cannot. This result is in agreement with the findings of Reference 9 and the theory of electrolytic conduction (Ref. 12) which indicate increased conductivity with increased temperature.

Since saturated steam conditions were maintained throughout the test, the temperature dependence could also have been interpreted as a pressure dependence. Pressure per se, though, is not the governing parameter in film conduction, but it is important in determining the conditions necessary for film formation. If a system is superheated, and at equilibrium, films will not form and the performance of the terminal block will be relatively good. Similarly, if the terminal block is above the dew point in an air environment, the same condition will exist. Alternately, if the terminal block temperature is below the dew point in an air environment, or if films have formed due to a cool terminal block being surrounded with steam and the system remains at saturation, films will form and remain on the surface of terminal block. These latter conditions are the situations that would nominally exist in a LOCA accident.

During the chemical spray periods of the Phase II tests, no effect of the chemical spray was observed. This finding was somewhat surprising since we expected the chemical spray to enter the conduit, penetrate down through the conduit-cable interstitial space, and drip onto the terminal blocks. This process would introduce Na^+ and OH^- ions to the surface film and thus enhance the film conduction. However, for our experimental configuration, this method of spray entry was apparently not operable. We also checked whether or not the steam in-rush would carry spray droplets to the terminal blocks by turning on the spray shortly before reintroducing steam into the chamber for the second steam ramp. Again, the results were negative. We conclude, therefore, that for our experimental configuration the NEMA-4 enclosures with unsealed conduit entries and 1/4" weep holes adequately protect the terminal blocks from the effects of chemical spray. This result corroborates the findings in Ref. 6.

4.0 Examples of Possible Terminal Block Effects

4.1 Transmitter Circuit. A pressure transmitter typically operates as a 4-20 mA device. At zero pressure 4 mA is allowed to flow in the circuit, at full pressure 20 mA is allowed to flow in the circuit. The key word here is "allowed". A transmitter essentially functions as a variable resistor in the circuit, limiting the amount of current flowing in its branch of the circuit to a value proportional to the input pressure; it is not a current source. This characterization is extremely simplified, but it captures the essence of circuit behavior and permits terminal block effects to be analyzed. Figure 6 shows how a transmitter might typically be connected in an actual plant application.

The transmitter will operate correctly as long as the voltage remains in a specified range. For example, a typical transmitter will operate to specification as long as the voltage across the transmitter terminals remains between 15 and 50 Vdc. The loop resistance external to the transmitter (from the current-to-voltage amplifiers, the cable, and the other external resistances) also may vary over a specified range depending on the voltage supplied to the transmitter. For a typical transmitter, if the power supply voltage is 45 Vdc, the external loop resistance may vary between 250 and 1500 ohms. Note from Figure 6 that the potential across the transmitter, ΔV_T, is essentially the potential across the terminal block and therefore would be the driving potential for any terminal block leakage current. ΔV_T can be expressed in terms of the normally constant power supply voltage, V_s, and the voltage drop, ΔV_e, across the external loop resistance, R_e:

$$\Delta V_T = V_s - \Delta V_e$$

$$= V_s - R_e I_L$$

where I_L is the total loop current. The leakage current, I_{TB}, across the terminal block is

$$L_{TB} = \frac{\Delta V_T}{R_{TB}}$$

where R_{TB} is the insulation resistance of the terminal block. The total loop current which will be observed in the control room as the transmitter signal will be the sum of the transmitter output current, I_T, and the terminal block leakage current:

$$I_L = I_{TB} + I_T$$

Under normal conditions, I_{TB} will be zero or negligibly small compared to I_T. However, under accident condition, I_{TB} can become a sizable fraction of I_T, and therefore, becomes a sizable portion of the total loop current sensed by control room instrumentation. The error, e, in the signal will simply be the ratio of the terminal block leakage current to the transmitter signal current. That is,

$$e = \frac{L_{TB}}{L_T}$$

By using Ohm's Law, we can express e in terms of V_s, R_e, R_{TB}, and I_T:

$$e = \frac{V_s - R_e L_T}{L_T(R_{TB} + R_e)}$$

Figure 7 shows a plot of the signal error as a function of transmitter output for common values of V_s, R_e, and several assumed values of R_{TB}.

The errors can be quite significant when the terminal block leakage current approaches the values of the transmitter signal or equivalently, when the terminal block IR approaches the values of transmitter input impedance. At 45 Vdc, the transmitter input impedance will vary from approximately 2 to 10 Kohms as its output varies from 20 to 4 mA. Hence, the terminal block may be viewed as a resistor in parallel with the transmitter and, as such, acts as a current divider. Figure 8 shows the current trace of total circuit current as a function of time for the terminal block connected in the transmitter circuit during our test. For the period of time covered by the plot, the transmitter was operating at ~4 mA base signal level. Clearly, the total circuit current observed is in agreement with the above analysis. Also visible is the return to the transmitter base current level during the cooldown period where the film vaporizes from the terminal block surface.

To illustrate the impact of these errors, suppose that the transmitter in question was a narrow range reactor coolant system (RCS) pressure monitor calibrated from 1700 to 2500 psi. Thus, each milliampere of signal corresponds to a 50 psi increment in pressure. The sensed pressure will be based on the total loop current, I_L. Assuming everything else in the circuit works perfectly, Figure 9 shows the readouts that would be observed in the control room for V_s = 45 Vdc, R_e = [illegible]0 ohms, and R_{TB} = 10,000 ohms. Note that the minimum reading is 1886 psi at the minimum transmitter current level of 4 mA.

One of the uses for narrow range pressure monitor is an actuation signal for high pressure injection (HPI). A common set point would be 1750 psi which is less than the minimum reading of 1886 psi caused by the summing of the 4 mA base current signal of the transmitter and the terminal block leakage current. The result is that actuation of HPI by low RCS pressure would not be automatically accomplished, and another means of actuation would have to be implemented. This type of error would also affect the pressure readings observed by the operator. Not only would the readings themselves be in error, the operator would be faced with a discrepancy in readings between narrow and wide range gauges.

<u>4.2 RTD Circuit</u>. RTD circuits are low voltage, low current circuits. They are not, however, immune to the effects of terminal blocks. An RTD circuit typically operates at 4 Vdc or less with currents in the range of 1 mA or less. The resistance in a typical RTD might vary from 200 ohms to 500 ohms over the full temperature range of the RTD. Figure 10 shows in a very simplified block form how an RTD circuit will look using a terminal block to connect the RTD to the remainder of the circuit. The IR of the terminal block is a parallel connection with the RTD resistance. Hence, the bridge or constant current circuit used to sense the resistance of the RTD is actually sensing the effective resistance, R_{eff}, of this parallel combination. R_{eff} is simply:

$$R_{eff} = \frac{R_{TB} R_{RTD}}{R_{TB} + R_{RTD}}$$

and the fractional error e is:

$$e = \frac{R_{RTD} - R_{eff}}{R_{RTD}} = 1 - \frac{R_{TB}}{R_{TB} + R_{RTD}}$$

For a typical 200-ohm RTD which varies in resistance from 200 to 480 ohms over its temperature range, a terminal block resistance of 10,000 ohms introduces an error in measured resistance of 2.0% at the low end of the calibration and an error of 4.6% at the high end. Figure 11 shows the two bounding curves of percent error in measured resistance for a commonly used 200-ohm RTD as a function of terminal block insulation resistance. For an RCS temperature monitor calibrated from 200°F to 750°F these resistance errors translate to a 7°F error at the low end and a 43°F error at the high end.

Since the parallel connection will make the measured resistance less than the actual RTD resistance, these temperature differences will always be on the non-conservative side. That is, the readout temperature will always be less than the actual temperature. Such an error may be significant in determining the degree of subcooling in reactor coolant. If the actual temperature is 640°F, an RTD calibrated as assumed above should have a resistance of 424 ohms at that temperature. A terminal block insulation resistance of 10,000 ohms would give an effective resistance of 407 ohms or a temperature readout of 606°F. Thus the degree of subcooling seen would be 34°F greater than what actually existed. If high pressure injection was maintaining RCS pressure at 1800 psia, (saturation temperature 621°F) an operator looking at 606°F would assume he has 15°F subcooling, whereas in actuality the temperature of 640°F would mean that the coolant is vapor. Thus, even relatively large terminal block IR's (e.g., 10,000 ohms compared to 424 ohms for the RTD) can have a significant impact on the perceived conditions in the plant.

5.0 Conclusions

We have tested terminal blocks at voltage levels representative of common applications in a simulated LOCA environment and measured their insulation resistances during the test. We observed insulation resistance decreasing to 10^2 to 10^5 ohms from initial values of 10^8 to 10^{10} ohms. These IR values are sufficiently low to affect high impedance instrumentation circuits by 0.2 to 170 percent with a nominal effect of 0.5 to 46 percent at the mid-range of instrument output. At 4 Vdc, insulation resistance was 5×10^3 to 7×10^4 ohms, values which are sufficiently low to affect RTD resistance measurements by 0.2 to 8 percent. Depending on the RTD calibration, this could translate to as much as a 40°F error in indicated temperature.

For our experimental configuration, the NEMA-4 enclosures with 1/4" diameter weepholes in the bottom and unsealed conduit entrances adequately protected the blocks from the effects of chemical spray. The NEMA-4 enclosures, however, do not offer any protection from the steam environment.

The illustrations of the transmitter circuit and the RTD circuit highlight the necessity of considering applications in determining whether or not terminal block performance will be adequate. Qualification tests have the objective of demonstrating that under specified environments the component being qualified will acceptably perform its function. Acceptance criteria should reflect this acceptable performance level. In the case of terminal blocks, however, the acceptable performance level varies with the application and hence the acceptance criteria should vary. Thus, it becomes important that a blanket, single-point acceptance criterion not be used, but rather data be provided on performance so that analysis of the effect on a particular application can be made. Alternately, if a single-point acceptance criterion is used, then it should be germane to the intended application. Acceptance criteria based on the failure of a 1 A fuse do not provide information about leakage currents less than 1 A. As we have shown, small leakage currents do exist, and may be significant to some applications.

<u>References</u>

1. C. Craft and R. Nelson, "Interim Report on the Assessment of Terminal Blocks Used in the Nuclear Industry," RS/4445/82/01, Sandia National Laboratories, February 1982.

2. Franklin Research Center, "Qualification Tests of Terminal Blocks and Splice-Insulating Assemblies in a Simulated Loss of Coolant Accident Environment, Phase A and Phase B," FRC Reports F-C5022-1 and F-C5022-2, October 1978 and November 1978. Prepared for Philadelphia Electric Company.

3. Franklin Institute Research Laboratory, "Qualification Test Program for Terminal Blocks," FRC Reports F-C4959, October 1978, F-C5205-3, October 1979, and F-A5385, October 1980. Prepared for Weidmuller Terminations, Inc.

4. Franklin Research Center, "Qualification Tests of Terminal and Fuse Blocks," Control Products Division, FRC Report F-C5143, July 17, 1980. Prepared for Amerace Corporation.

5. Wyle Laboratories, "Qualification Test Program for Terminal Blocks," Wyle Report 45603-1, February 1982. Prepared for Marathon Special Products.

6. Wyle Laboratories, "Loss of Coolant Accident Testing of Five Weidmuller Terminal Blocks for Washington Public Power Supply System" Wyle Report 58687, Wyle Laboratories, Wyle Norco, California, June 29, 1982. Prepared for WPPSS and Weidmuller Terminations, Inc.

7. MultiAmp Corporation, States Division, "Test Report on States Terminal Blocks and Test Switches," States Nuclear Test Report No. 8919. Prepared for States Company by Acton Environmental Testing Corp.

8. Phonix Klemmen, Documentation to Support Qualification of Phonix Terminal Blocks, consisting of the following test reports:

   a) Bundesanstalt fur Materialprufung, Berlin, Test Reports 3.42/4444 and 3.43/4444-1
   b) Institute National des Radioelements, Fleurus, Belgium, Test Report Q. N. 21 and Q. N. 24
   c) Societe pour le Perfectionnement des Materials et Equipments Aerospertiaux, Velizy-Villacoublay, France, Test Reports LV24633 and LV14771/1
   d) Wyle Laboratories, Scientific Services and Systems Group, Norco, California, Test Report 58610

9. O. Stuetzer, "Electrical Insulators in a Reactor Accident Environment, SAND80-1957, NUREG/CR-1682, Sandia National Laboratories, January 1981.

10. C. Craft, "Screening Tests of Terminal Block Performance in a Simulated LOCA Environment," SAND83-1617, NUREG/CR-3418, Sandia National Laboratories. To be published.

11. The Institute of Electrical and Electronic Engineers, Inc., IEEE Standard 323-1974. IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, IEEE 1974.

12. S. Glasstone, An Introduction to Electrochemistry, D. Van Nostrand Company, 1942.

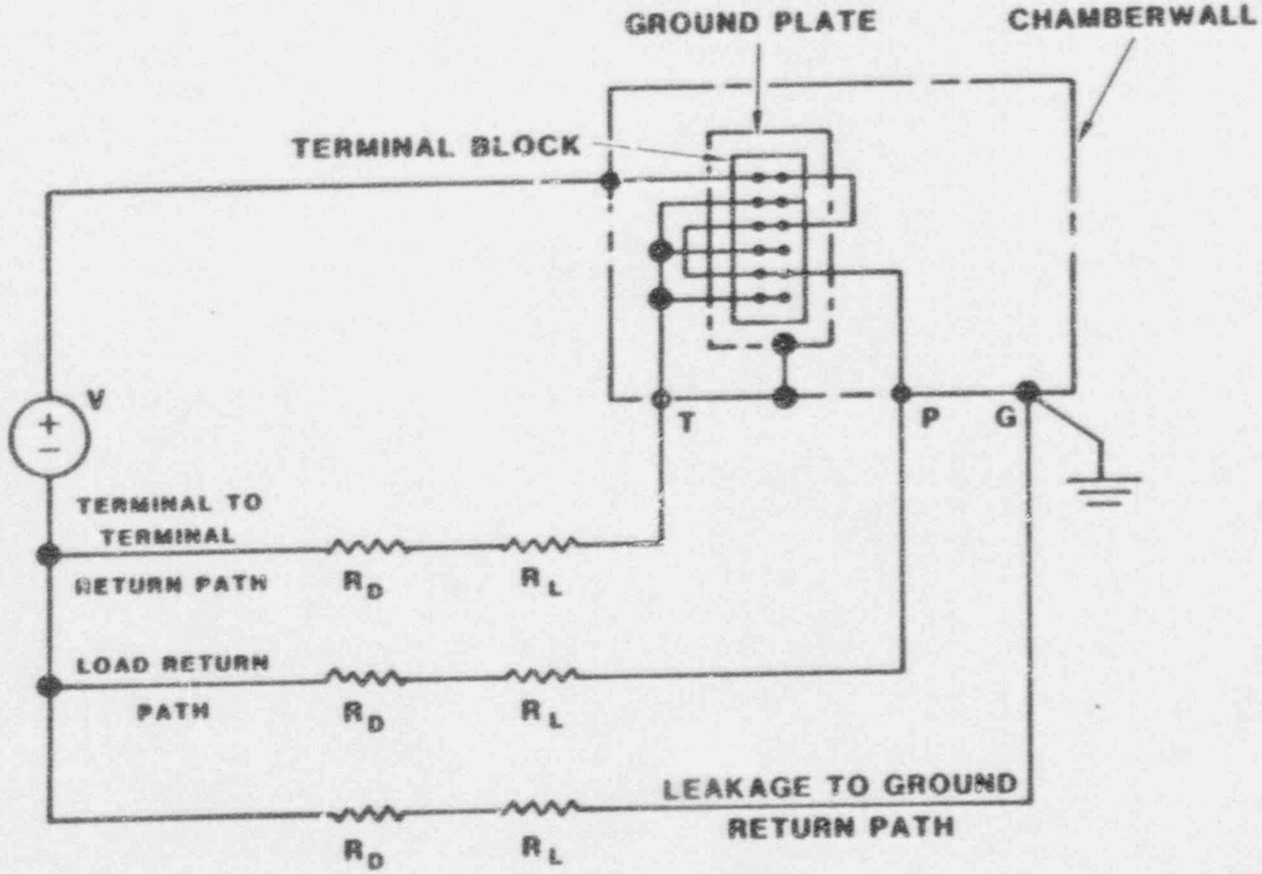


Figure 1: Wiring Schematic for the Phase I Terminal Block Test
(Note the serpentine connection on the terminal block)

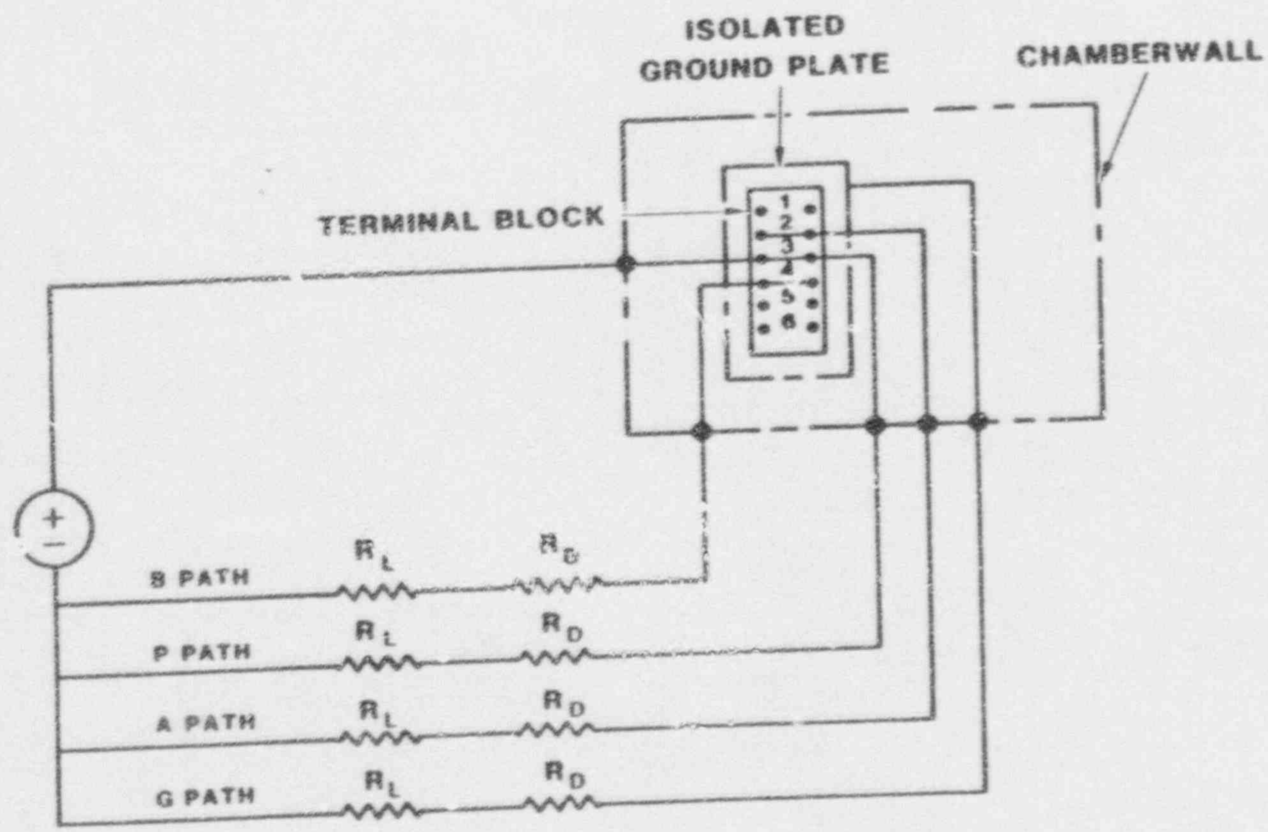


Figure 2: Wiring Schematic for the Phase II Terminal Block Test
(Note the once through connection on the terminal block)

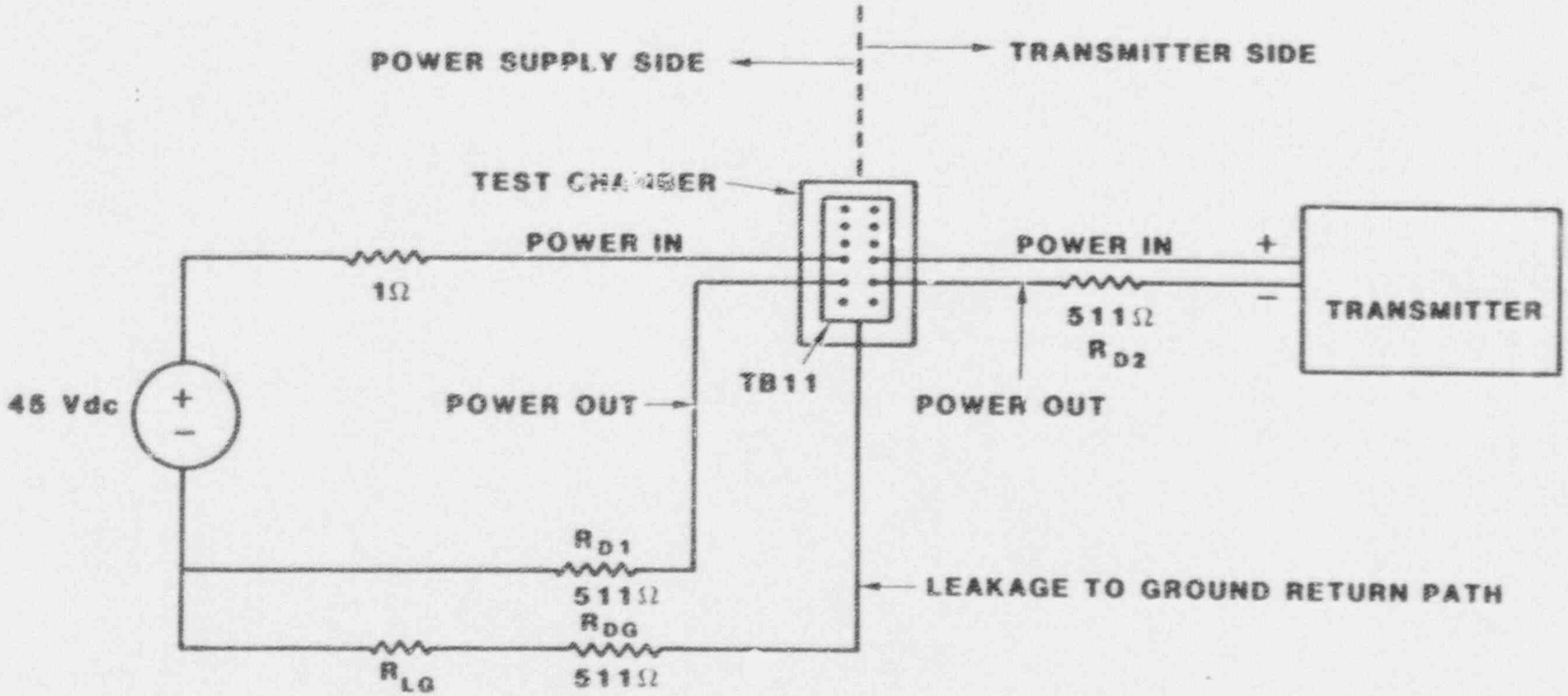


Figure 3: Wiring Schematic for the Transmitter Circuit Tested in the Phase II Terminal Block Test

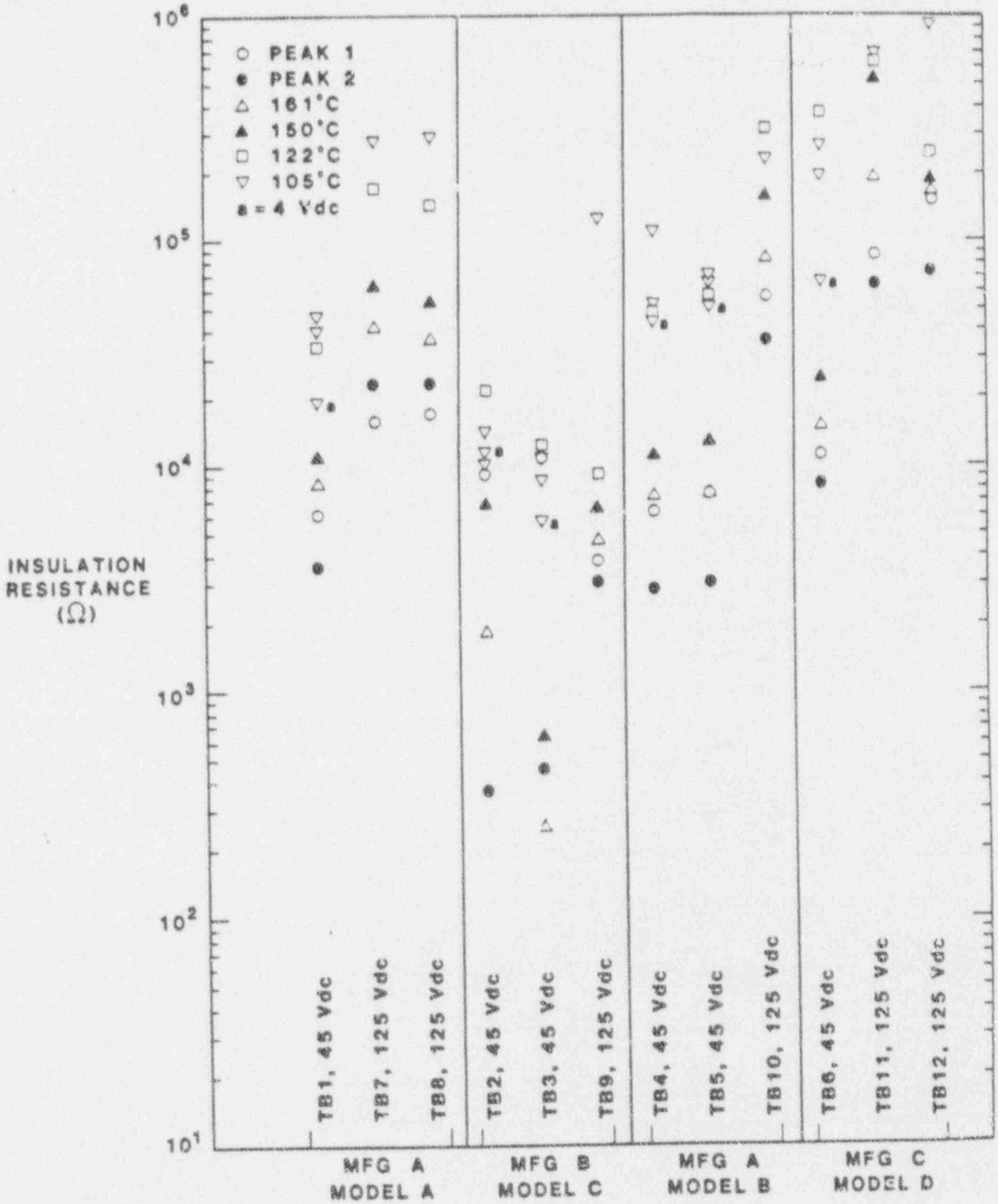


Figure 4: Insulation Resistance for Phase I Terminal Blocks

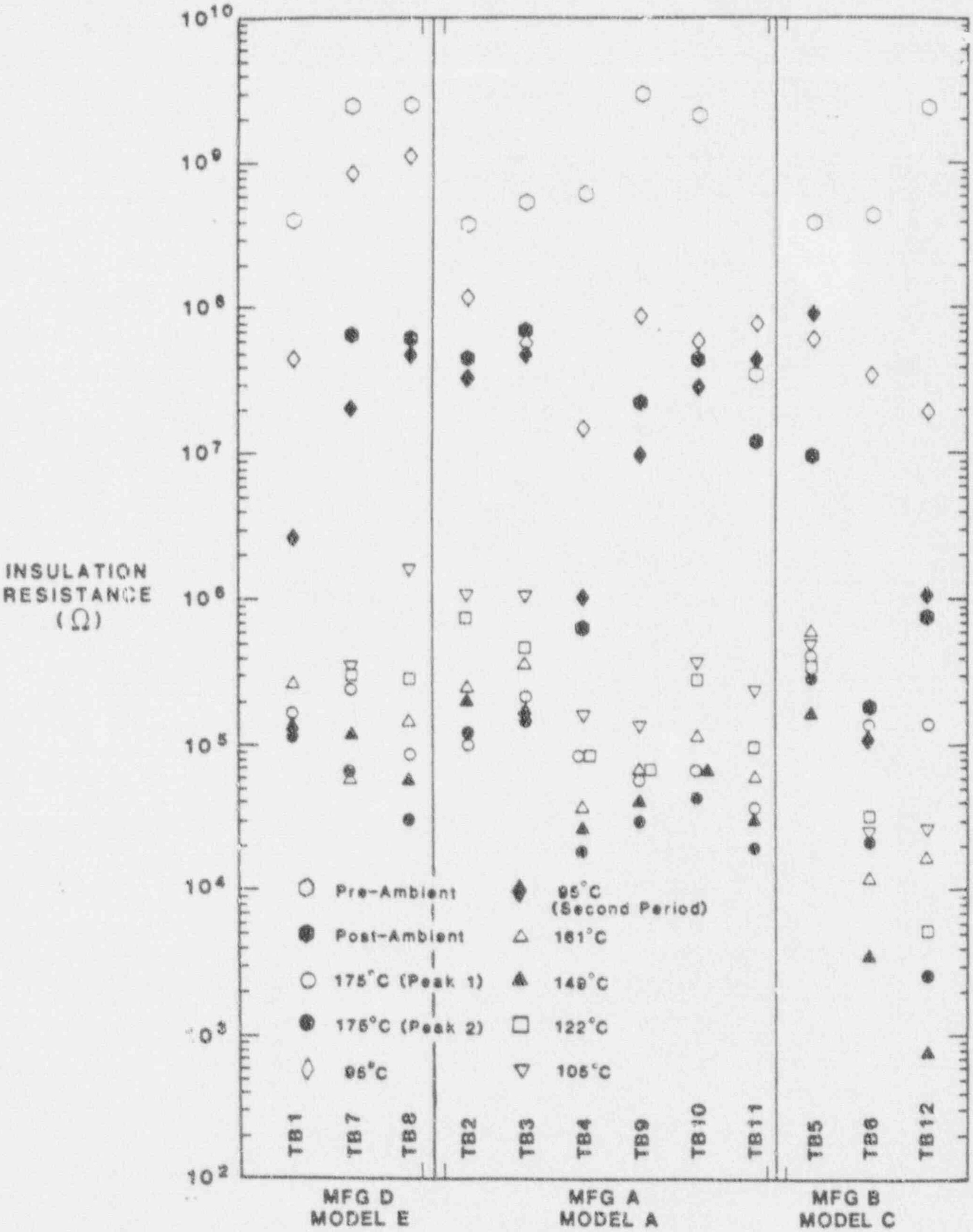


Figure 5: Insulation Resistance A for Phase II Terminal Blocks (Terminal Blocks 1-6 powered at 125 Vdc 1 A and Terminal Blocks 7-12 powered at 45 Vdc 20 mA)

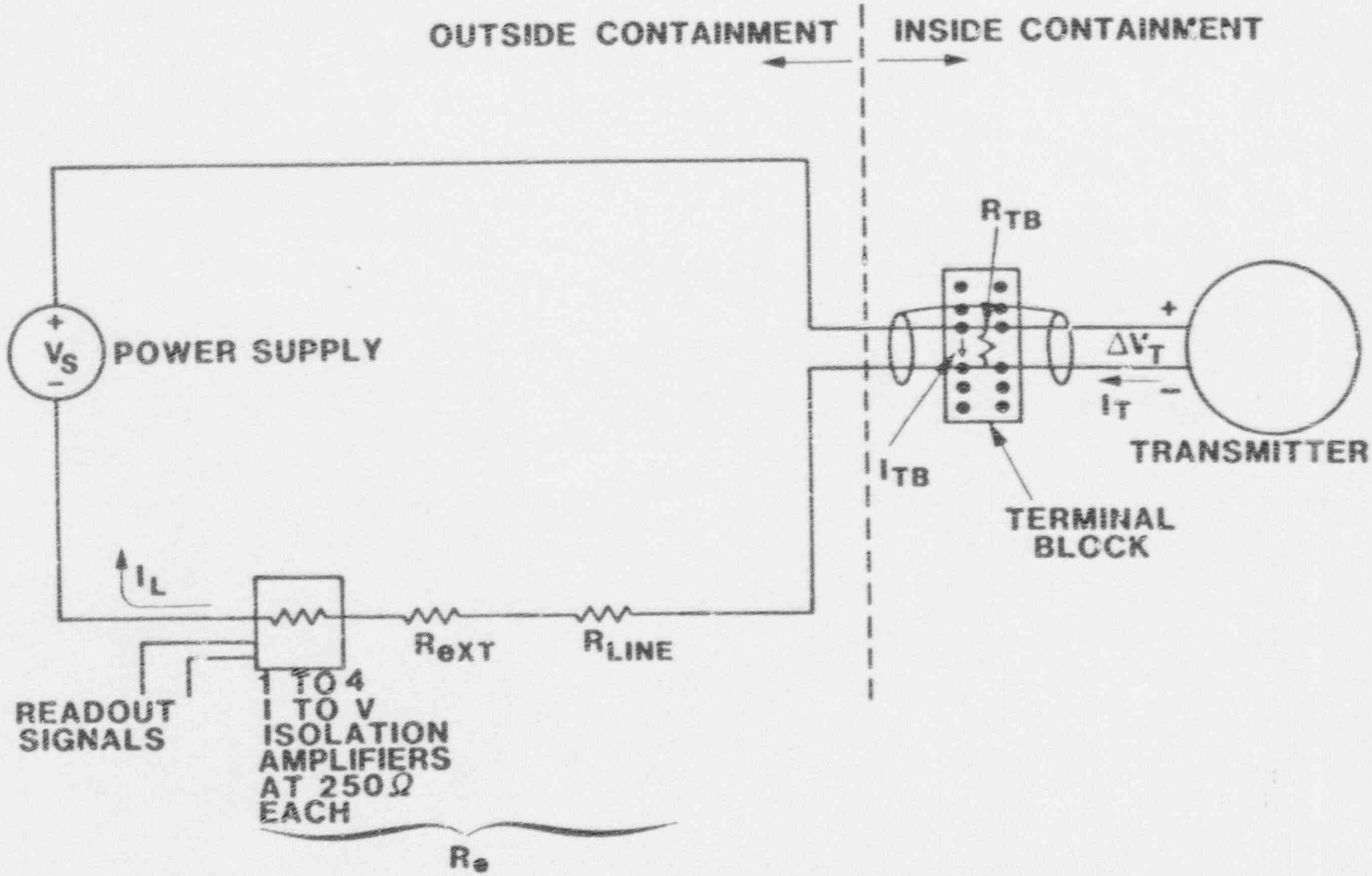


Figure 6: Simplified Schematic of a Typical Transmitter Circuit in a Plant

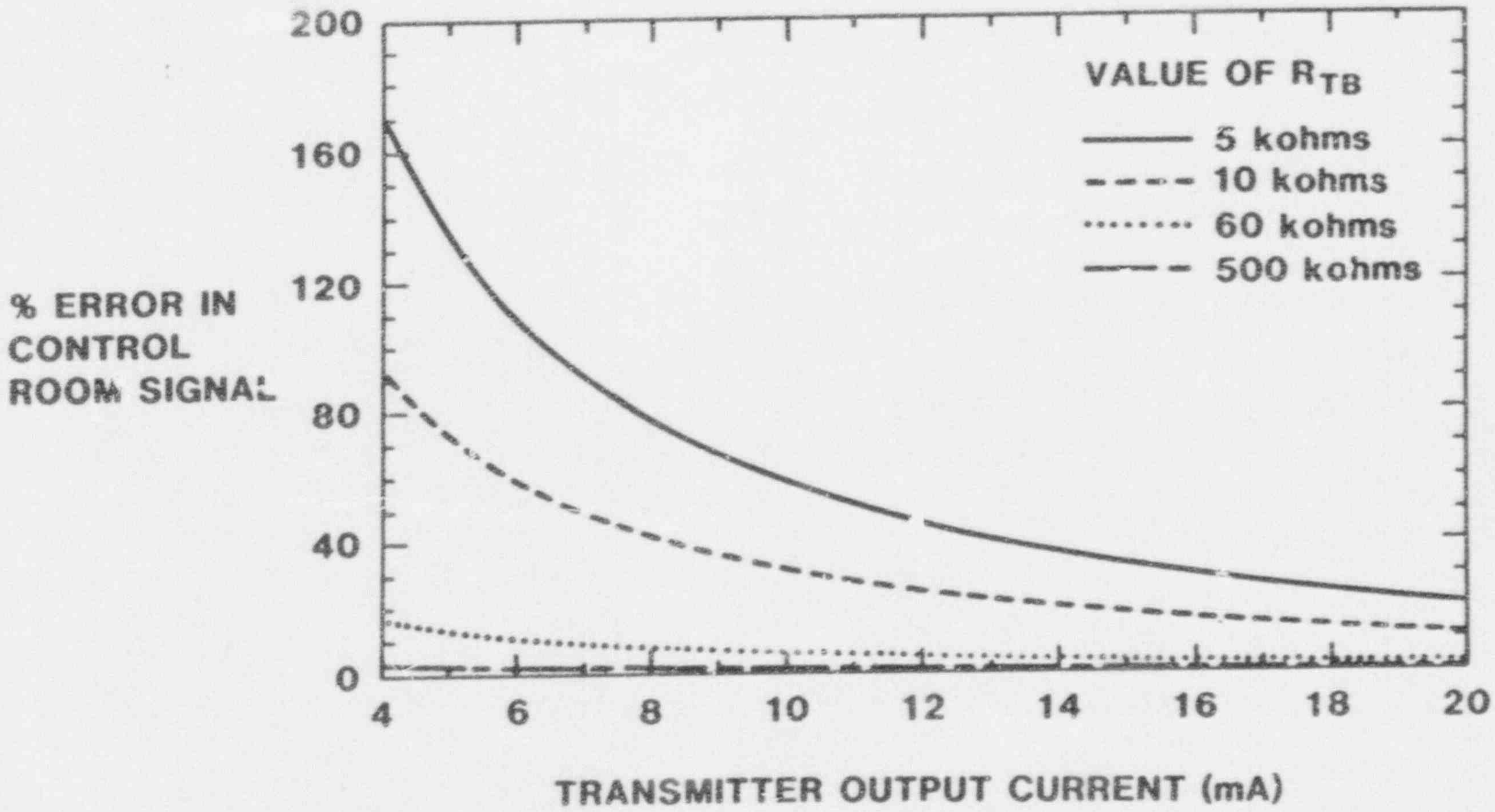


Figure 7: Percent Error in Transmitter Circuits for Selected Values of Terminal Block Insulation Resistance. (R_e = 1000Ω and V_s = 45 Vdc)

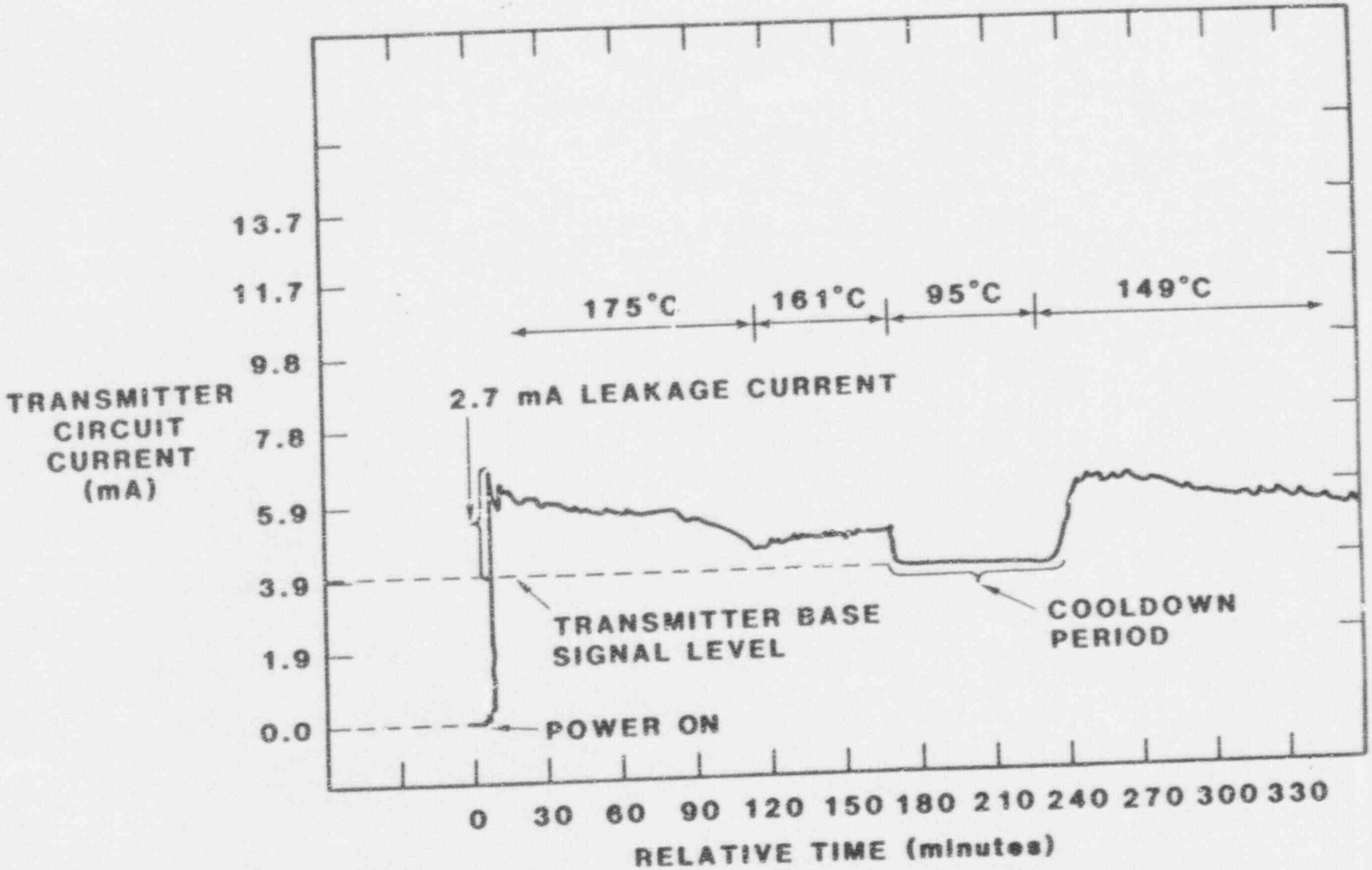


Figure 8: Total Current Trace of Transmitter Circuit During LOCA Simulation

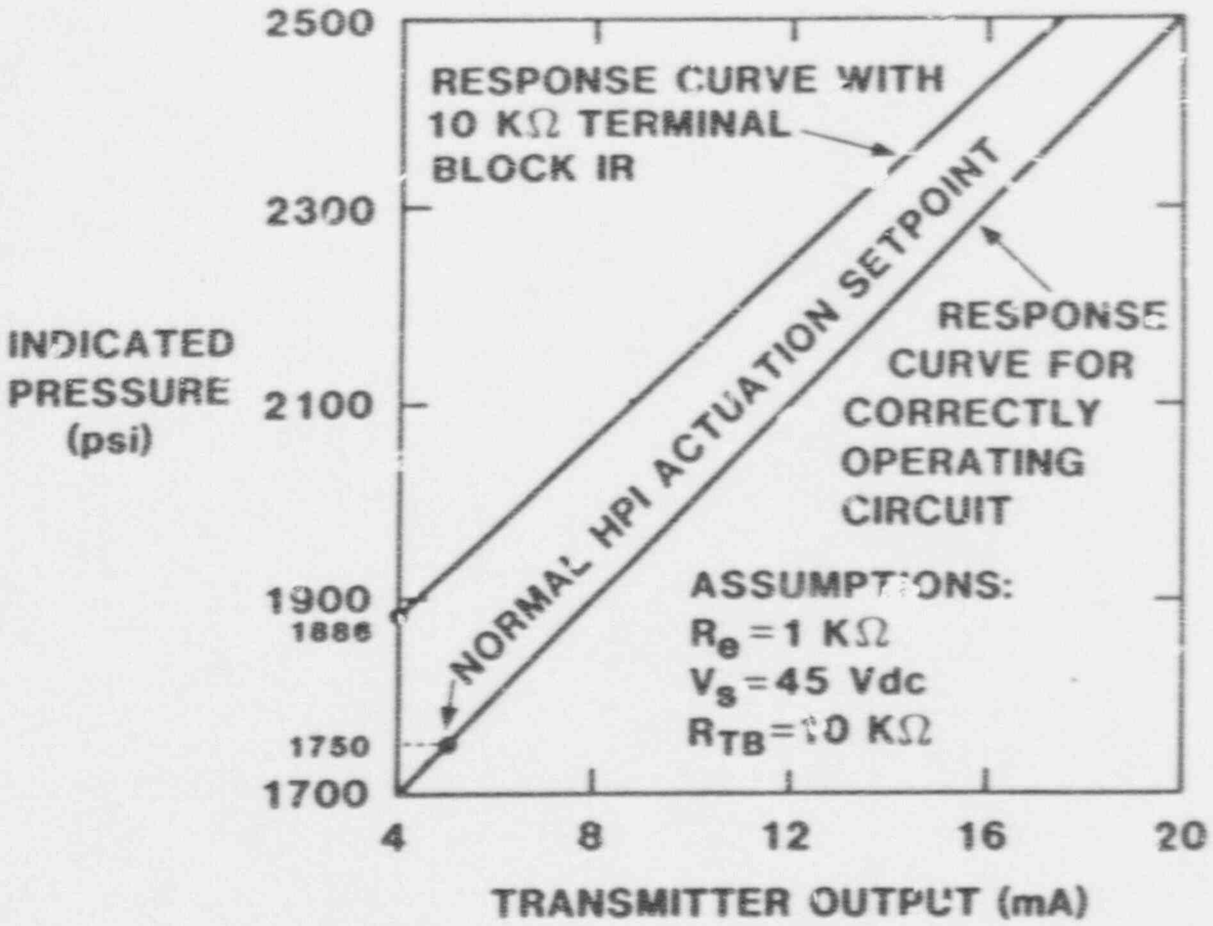


Figure 9: Indicated Pressure as a Function of Transmitter Output for a Correctly Operating Circuit and Circuit With Terminal Block Insulation Resistance Assumed To Be 10 KΩ

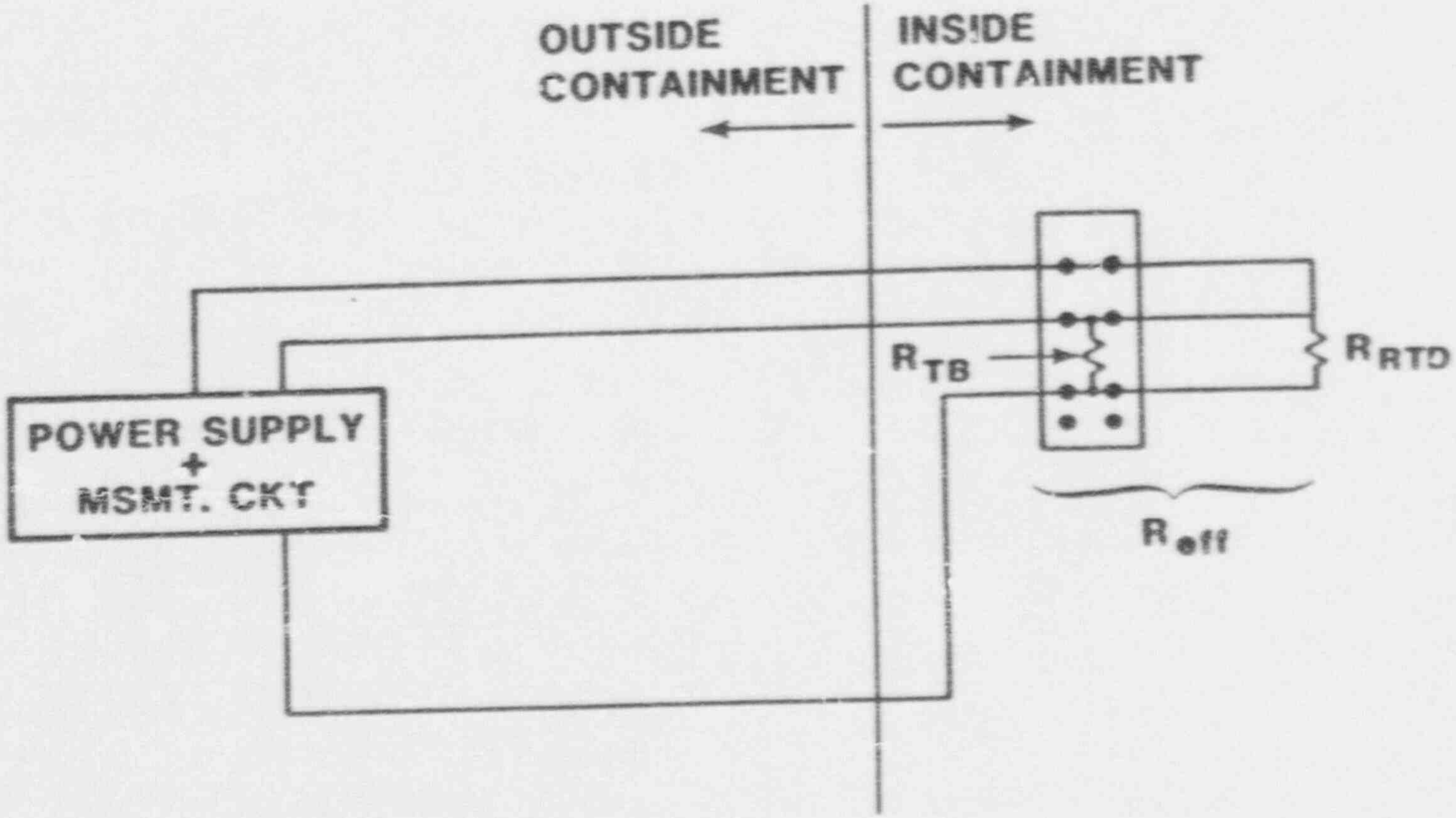


Figure 10: Simplified Block Diagram of a 3-Wire RTD Circuit Showing Parallel Connection Between Terminal Block Insulation Resistance and the Resistance of the RTD Sensing Element

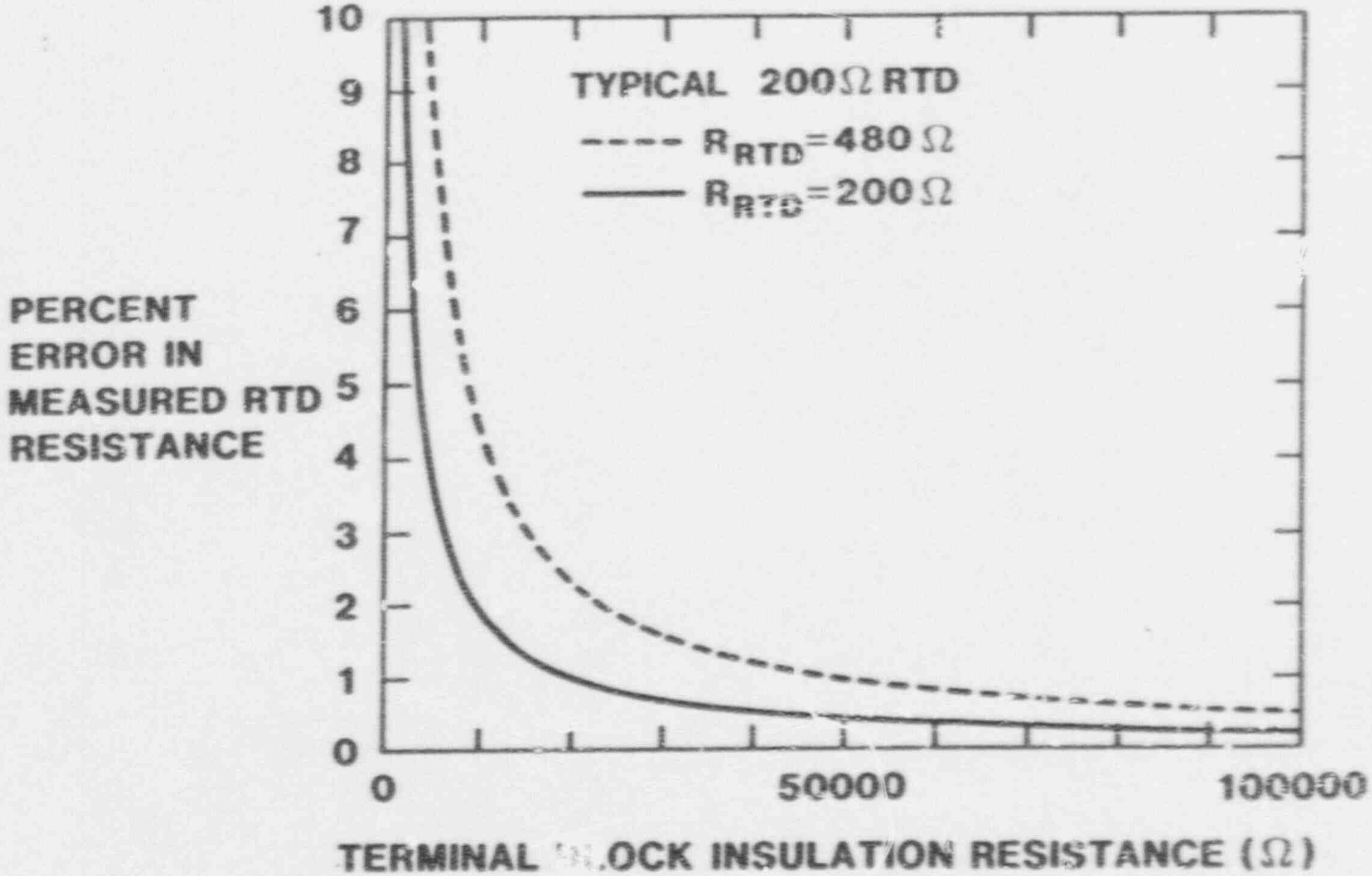


Figure 11: Percent Error in the Resistance Measurement of an RTD as a Function of Terminal Block Insulation Resistance

FROM A Review of Equipment Aging Theory and Technology. EPRI NP-1558 Project 890-1 Final Report Sept. 1980

Section 2

The Common Failure Problem

Since the common failure problem is at the root of concern for equipment aging, an effort will be made to define the problem and to clarify the terms used in discussing it. While the terms common mode *failure* and common failure *mode* are used more or less interchangeably, the phrase 'common failure *mode*' focuses on the mechanism (or mode)* which is common to the failure, whereas 'common mode *failure*' emphasizes the failure due to a common mechanism. It would thus appear that a common failure mechanism or *mode*, if undetected or undiscovered, could lead to a failure which would then be described as a common mode *failure*. A common failure *mode* becomes a potential source of common mode *failure*.

IEEE Std 380-1972 defines common failure *mode* as a "mechanism by which a single design basis event can cause redundant equipment to be inoperable." This definition could be interpreted as excluding causes which are not design basis events, therefore excluding causes which would make the equipment inoperable before the design basis event (DBE). This meaning apparently is not intended since several authors—among them Cain (344), Jolley and Wreathall (662) and Gaugloff (649)—*include causes other than design basis events in their discussion of the common failure problem. Some of these authors suggest subclassifications of common failure mode* by distinguishing among various causes. The causes include design inadequacies, manufacturing shortcomings, and age degradation in normal and DBE conditions (344). Gaugloff extends this with an all-inclusive listing which encompasses catastrophic causes. Jolley and Wreathall make a distinction between internal or *intrinsic* causes and external or *extrinsic* causes. They include catastrophic conditions of fire, flood, tornado and earthquake as extrinsic causes, referring to this kind of cause as *common system faults*. Human error is included as a cause of common failure by both Gaugloff and by Jolley and Wreathall.

The following two features are usually considered essential for failures to be classified as common mode *failures*:

1. The failures occur in each of two or more redundant paths in a safety system.
2. The failures are related to each other by a common or shared cause, mechanism, stress or other similarity.

---

*Mechanism is defined as the basic physical cause of failure, such as corrosion or wear. Mode is defined as the manner or method of failure, such as the opening of a circuit due to corrosion or the seizure of a bearing due to wear.

Jolley and Wreathall state as additional preconditions that the failures must occur prior to, or at a time when demand could occur, and they must be undetected or unexpected failures. These are features relating to failures of elements of a system which together lead to the system failure.

The mechanisms or modes which are common to the elements can originate from many kinds of shared similarities. The commonness can occur at any point in the history of a device, from the original concept through the various steps of logical design, instrument design, manufacturing, testing, qualification, installation, checkout, service, and operational stages. Thus, a temporal classification of causes can be made. At each of these stages the fault peculiar to the stage can occur, be discovered and rectified. The common fault of one stage may also be discovered in a later stage, but then it is often difficult to rectify or eliminate. Each stage appears to be sufficiently different from the others to merit a subclassification, as suggested in Table 2-1.

Table 2-1

SUGGESTED COMMON FAILURE MODE TYPES

Type 1.	Conceptual or engineering design error or inadequacy.
Type 2.	Manufacturing error, shortcoming or poor practice.
Type 3.	Testing or qualification error or omission.
Type 4.	Installation error, omission or lack of validation of proper installation.
Type 5.	In-service aging or deterioration due to environmental or operational stress. Stresses include normal and abnormal DBE and post-DBE stresses.
Type 6.	Operational misuse. This includes human errors of commission or omission.

Countless examples, either discovered or suspected, could be given for each of the common failure mode types listed in Table 2-1. That many (and perhaps most) of these faults have been detected, corrected or circumvented by good engineering practice, thoroughness of review, diversity of design, physical separation, inspection, and administrative controls, is a tribute to the integrity and competence of those charged with the responsibility of performance and safety. All of the problems, however, have not been solved.

The purpose of the material covered in this report is directed toward, and peripheral to, common failure *mechanisms or modes* primarily of Type 5 and related to Type 3. Failures of Type 5, it is hoped, will be more readily recognized, evaluated, and reduced or eliminated by the proper application of accelerated aging procedures at the Type 3 level.

For few, if any, of the failure types is there an analytical or physical procedure which will insure that no cause is overlooked. However, there are methods for detection, discovery and correction of each type of common failure *mode* listed in Table 2-1. In manufacturing, for example, quality control of various levels of sophistication is used to insure the production of components and assemblies of uniformly high quality. It is conceivable that successful quality control could also ensure the perpetuation of an undiscovered common failure *mode* in each of the final products being controlled. However, this observation is not intended to suggest less quality control but to point out a potential pitfall that should be recognized.

The philosophy of diversity, which reduces the commonality among redundant safety systems, is a principal method of decreasing the possibility of unknown common failure *modes*. Diversity is achieved by introducing as many differences as possible into the design and construction of the systems, e.g., by use of different operating principles, different types of components and materials, different manufacturers and different locations in the plant. Diversity can be applied to any of the types of common failure *mode*; however, a higher level of diversity is probably possible with the first three types listed in Table 2-1 than with the last three types. In-service deterioration due to environmental and operational stresses, a common failure *mode* of Type 5, can extend over many diverse systems, and hence requires special attention. A Type 6 failure mode, human error or operational misuse, is a most difficult area in which to apply the philosophy of diversity. This mode will not be considered in this report.

The fact that diversity can reduce the probability of common failure due to aging should not diminish efforts to attack the problem of aging. Measuring the degree of diversity is largely a qualitative process, and there is no way to assure that common failure mechanism or mode is not present in even highly diverse systems.

Common-mode failure is generally distinguished from *random* failure in the qualification of safety-system equipment. As discussed in Section 5, random failure is often applied loosely to the constant failure rate region of the classic "bathtub" characteristic curve of hazard rate vs. time. Failures that occur in this region are thought to be the consequence of random variations among material and component properties and manufacturing processes; in particular, they are usually regarded as being independent of degradation due to aging or wearout. Since random failures are not likely to cause simultaneous malfunction of redundant safety systems, they are not a basis for rejection of equipment for use in safety systems of nuclear power generating stations. Surveillance and maintenance procedures are expected to reveal random failures so that corrective action can be taken.

If a test specimen fails during a qualification test, it is necessary to determine whether the failure was of the random or common-mode type. However, distinguishing between these two types of failure is not easily accomplished. If it were economically feasible to subject a large number of specimens to a qualification test, it would be possible to make the distinction between random and common-mode failures on a statistical basis. However, this is rarely a feasible approach. Even in the case of the simplest test, that of coating specimens consisting of small coated metal panels (a passive type of specimen that does not require any monitoring of performance *during* a test exposure but only an evaluation of results *after* a test), the number of specimens required to produce statistically significant results tends to make the test unreasonably expensive. Generally, it is necessary to analyze any failures carefully to determine the cause of failure and then to determine whether the cause is a form of design deficiency or one that can be classified as random. For example, if a transistor fails in an electronic instrument, it is necessary to determine whether failure is due to causes such as excessive thermal or electrical stress, in which case it would be classified as a common-mode failure requiring a design change, or whether there is truly no design-related weakness responsible for the failure, in which case one can (at least provisionally) classify the failure as random.

It is advisable to monitor the performance in service of any safety-system equipment that was the subject of a random failure during qualification, so that the service record can provide a further check on the validity of the randomness of the failure. Such monitoring should be keyed to the type of 'random' failure that occurred during qualification. For example, the procedures for maintenance and testing of the equipment in the plant could specify that the particular component in question be inspected separately (not just as an element of an assembly) and that any evidence of degradation be used to re-evaluate the adequacy of the component. Maintenance and testing intervals of greater than normal frequency could be specified in these cases.

A critical need for high reliability has existed previously in weapons and space systems, where the lifetime requirement (5 to 10 years) has been relatively short compared to the desired lifetime (up to 40 years) for nuclear safety systems. The weapons and space programs have used accelerated *testing* to identify failure modes in advance of field application, to obtain failure rate estimates and to provide a basis for making selections among alternative materials, components and devices. On the other hand, the object of accelerated *aging*, in a program of equipment qualification, is to put a specimen into a condition simulating its ability to function as required during and following a design basis event that may occur after as much as forty years of service. Often, the equipment has already been selected, subject to being qualified, and it may be on order or in various stages of installation in a power plant under construction.

Conclusion

In-service aging due to environmental and operational stresses can lead to essentially simultaneous failure of redundant safety systems when there is a demand for a safety function in a nuclear power generating station. Because it is the most prevalent source of potential common mode failures, equipment aging merits the utmost attention in the process of qualifying equipment for use in safety systems. Although it is acknowledged that so-called random failures are not likely to cause simultaneous failure of redundant safety systems, and this type of failure during qualification does not automatically lead to rejection of the equipment being tested, great care must be taken in analyzing an apparently random failure to provide assurance that it is not related to a deficiency of design or manufacture.

Inspecting

Interfaces and Installation Practices

in Qualification Tests

Similar inspection techniques can be used for interfaces and installation.

1. consistancy checks

2. past experience

Interfaces must be included in qualification.

Example

Does a qualified pressure switch

plus

qualified lead wires

equal

a qualified system?

Not necessarily - what kind of connections are used?

Most problems with qualifying interfaces are related to moisture.

1. corrosion of parts
2. electrical shorts / grounds
3. some problems obvious, some not

IEEE 323-1974 defines "interface" as "a junction or junctions between a Class IE equipment and another equipment or device. (Examples: connection boxes, splices, terminal boards, electrical connections, grommets, gaskets, cables, conduits, enclosures, etc.)"

IEEE 323-1974 goes on to say "the capability of all Class 1E equipment, including interfaces, of a nuclear power generating station for performing its required function shall be demonstrated."

IEEE 323-1974 further states "Principles and procedures for demonstrating the qualification of Class IE equipment include .... qualification of any interfaces associated with Class IE equipments."

The standard is specific in that it requires qualification of interfaces, but does not specify what constitutes adequate qualification.

There are several cases to consider.

1. Interfaces are not considered in the qualification package.

   obvious non-conformance

2. Interfaces are considered, but the qualification package contains insufficient information to demonstrate that the interface is qualified.

   also non-conformance. could also be written as "insufficient documentation" or "qualification file not auditable"

There are several cases to consider.

3. Interfaces are considered, and there is sufficient information to decide if the interface is qualified, but the information shows that, in fact, the interface is not qualified.

4. Interfaces are considered, and there is sufficient information to demonstrate qualification of the interface.

3rd & 4th case are really the same, except that 3 results in a non-conformance and 4 does not.

Inspection must assess technical adequacy.

1. Is test set-up consistent with the way the equipment will be connected in actual service?

2. Has past experience uncovered any problems in similar situations?

Coaxial cable example

1. moisture intrusion

2. Calvert Cliffs

Installation

If equipment is not installed in a test the same way it is installed in a plant, then the qualification may or may not be valid.

Installation includes such things as

1. orientation
2. lubricants
3. seals
4. torquing requirements
5 cooling and ventilation
6. mounting procedures

Requirements

Section 6.3.1.2 of IEEE 323-1974 states "Equipment shall be mounted [in a test] in a manner and a position that simulates its expected installation when in actual use unless an analysis can be performed and justified to show that the equipment's performance would not be altered by other mean of mounting. By 'manner' is meant the means to be used such as bolts, rivets, welds, clamps, etc. By 'position' is meant the spatial orientation with respect to the gravitational field of the earth. The effect of any interposing structures which are required for installation, such as control boards, stands, legs, pedestals, etc, shall be taken into account in specifying the test mounting."

Section 6.3.1.3 of IEEE 323-1974 states "Equipment shall be connected [in a test] in a manner that simulates its expected installation when in actual use unless an analysis can be performed and justified to show that the equipment's performance would not be altered by other means of connection. By 'manner' is meant the means to be used in connection to equipment such as wiring, connectors, cables, conduit, terminal blocks, service loops, piping, tubing, etc."

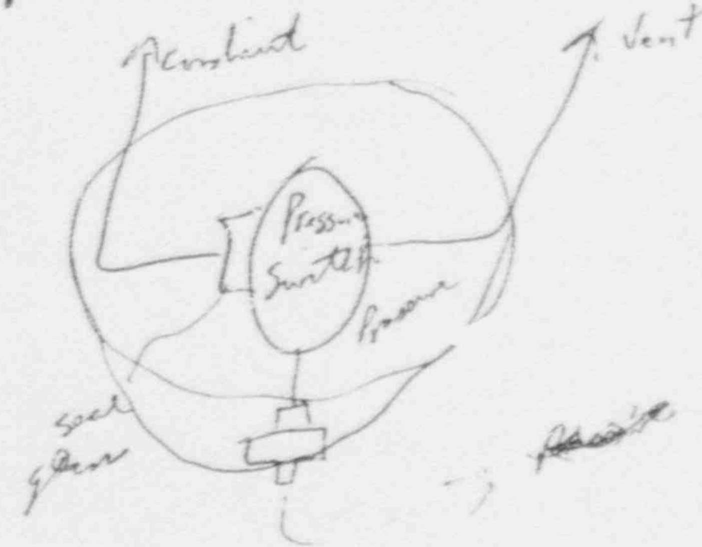
Once again, consistency checks are a useful inspection technique.

1. site verification - Is actual installation consistent with specification / qualification

2. qualification testing - Does installation in test match specified service installation? If not, is adequate justification given for difference?

Example

pressure switch venting



SCR Pressure Switch

INTERFACES and INSTALLATION

Interfaces and installation are two related areas that are sometimes overlooked or insufficiently addressed in a qualification effort. Because of this, and because they are important to consider when qualifying equipment, they are good areas to examine during an inspection. The two subjects are discussed separately here, but because they are related, similer inspection techniques can be employed.

Interfaces

Background

Equipment classified as Class 1E is normally a sub-set of a system. Because it usually is not feasible to qualify an entire system at once, it is necessary to qualify parts of a system one or several at a time (i.e. a pressure switch and its lead wires as opposed to the entire system including junction boxes, penetrations, etc.). When testing portions of a system it is very important to consider the interfaces between the various parts. As a simple example, consider the pressure switch and lead wires. It is possible to test the switch without the lead wires by connecting the switch to special connections during the test. It is also possible to qualify wire without connecting it to anything other than special test connections. Individually these components may pass the qualification test, implying that if they are used together the resulting combination will be qualified.

However, unless the wire and switch are tested together or a justified analysis shows otherwise, there is no assurance that the connections between the two are qualified. It is possible that moisture from the LOCA steam environment could condense onto the the connections, causing them to short to each other or ground.

It turns out that most of the problems with interfaces are related to moisture. These problems are usually due either to corrosion of parts or shorts and grounds. Some of them are not all that surprising: for example, weep holes in junction boxes relieve pressure but let water in. Some of the problems, however, are much more subtle and require some insight on the mechanisms at work. They will be illustrated in the examples in this section.

Requirements

The information in this section is aimed at qualification efforts that list IEEE 323-1974 as an applicable document. This is consistant with most of the packages reviewed on vendor inspections, but it is likely that the later IEEE standards do not apply to some of the ol[illegible] plants. The older standards (e.g. IEEE 323-1971) are much less specific and are more difficult to inspect to; the information presented here will serve as technical background on which to base decisions regarding qualification to the older standards.

IEEE 323-1974 defines "interface" as "a junction or junctions between a Class 1E equipment and another equipment or device. (Examples: connection boxes, splices, terminal boards, electrical connections, grommets, gaskets, cables, conduits, enclosures, etc.)"

IEEE 323-1974 goes on to say " The capability of all Class 1E equipment, including interfaces, of a nuclear power generation station for performing its required function shall be demonstrated."

IEEE 323-1974 further states "Principles and procedures for demonstrating the qualification of Class 1E equipment include.....qualification of any interfaces associated with Class 1E equipments."

Inspecting Interfaces

It can be seen from the above that IEEE 323 is specific in that it requires qualification of interfaces, but it does not specify what constitutes adequate qualification. So, how does one inspect the qualification of interfaces when there are few specific quidelines? There are several cases to consider when inspecting a given qualification package:

1. Interfaces are not considered in the qualification package.

2. Interfaces are considered, but the qualification package contains insufficient information to demonstrate that the interface is qualified.

3. Interfaces are considered and there is sufficient information to decide if the interface is qualified, but the information shows that in fact the interface is not qualified.

4. Interfaces are considered, and there is sufficient information to demonstrate qualification of the interface.

The first case is straight forward; if interfaces are not considered then the qualification package clearly is not in conformance with the requirements. The second case is also fairly simple, but the nonconformance could also be written as 'insufficient documentation' or 'qualification file is not auditable.'

The third and fourth cases are really the same, except that the third case results in a non-conformance and the fourth case does not. For these two situations, the inpection process is the same. On the surface, it appears that interfaces have been considered carefully. Thus an assessment of the technical adequacy must be made. Two approaches can be used here: One is to see if the test set-up is consistent with the way the equipment will be connected for service in a reactor. For example, if coaxial cable is to be used in actual service, the test should include the coaxial connection (as opposed to a special test set-up that will qualify the component without the connections). The other approach is to use past experience as a quide to find problems. For example, if Company A discovered a problem with the qualification of a certain kind of interface, and Company B is qualifying a similer device, the inspector could examine Company B's efforts to ensure that the same problem is not present. An experience qualifiying coaxial cable illustrates both approaches.

Installation

Background

The purpose of this section is to point out the importance of simulating the installation of equipment during a qualification test. The specifications for most equipment contain important installation instructions that are essential for proper operation of the equipment. These specifications include such things as orientation, lubricants, seals, torquing requirments, cooling and ventilation, and mounting procedures. If the equipment is not installed in a test the same way it is installed in a plant, then the qualification may or may not be valid.

Requirements

Again, this section is aimed at qualification efforts thst are consistant with the 1974 version of IEEE 323. Equipment qualified to IEEE 323-1971 is more difficult to inspect because IEEE 323-1971 is less specific, but the information presented here provides a technical basis on which to judge older qualification efforts.

Section 6.3.1.2 of IEEE 323-1974 states "Equipment shall be mounted [in a test] in a manner and a position that simulates its expected installation when in actual use unless an analysis can be performed and justified to show that the equipment's performance would not be altered by other mean of mounting. By 'manner' is meant the means to be used such as bolts, rivets, welds, clamps, etc. By 'position' is meant the spatial orientation with respect to the gravitational field of the earth. The effect of any interposing structures which are required for installation, such as control boards, stands, legs, pedestals, etc, shall be taken into account in specifying the test mounting."

Section 6.3.1.3 of IEEE 323-1974 states "Equipment shall be connected [in a test] in a manner that simulates its expected installation when in actual use unless an analysis can be performed and justified to show that the equipment's performance would not be altered by other means of connection. By 'manner' is meant the means to be used in connection to equipment such as wiring, connectors, cables, conduit, terminal blocks, service loops, piping, tubing, etc."

Inspecting Installation

It is clear from the above quotations from IEEE 323 that simulating the equipment's mounting is a requirement. If equipment mounting and connections are not considered, then obviously the qualification effort is not in conformance with the standard. But often the problem that should be addressed during an inspection is not whether installation requirements were considered, but whether they were considered adequately and/or correctly. To assess the technical adequacy of the installation the same two approaches used for inspecting interfaces can be used. The mounting and connection proceduresused in the test should be consistant with the mounting and connection requirements for actual use. Note that this does not mean that they have to be exactly alike, but rather the test must simulate or be more conservative than the actual application. Of course, if the mounting and connection procedures do not match those for actual intallation, proper justification for the differences must be provided. The following example demonstrates the importance of simulating mounting procedures.

Example

In this case, a pressure switch being qualified was not installed in the test exactly as it would be in actual service. This resulted in a situation where a significant failure of the switch could go undetected in the test. By "significant failure" it is meant the failure in actual service could result in loss of a safety function. The details follow:

The switch was installed in the test in such a way that it was vented to the outside, thereby causing the back side of the diaphram to always see ambiant pressure. Because of this, it is likely that a failure of the seal would have gone undetected during the test. In other words, ambiant pressure would have been maintained inside the switch (and on the back side of the diaphram) despite the leak. During actual use of the switch (whether inside or outside containment) if the switch is not vented in a similar manner, a leak in the seal would cause the pressure on either side of the diaphram to equalize; this pressure equalization would cause failure of the switch to operate properly.

There is no specific procedure to follow to check for deficiencies such as this -- instead the inspector must check for consistancy in each individual case. Sometimes past experience can be used as some problems are likely to recur. This is especialy true where things like orientation (position) of a piece of equipment are involved, as they apply to many types of equipment.

EARTHQUAKE CHARACTERISTICS

AND

SEISMIC QUALIFICATION

DR. MICHAEL P. BOHN

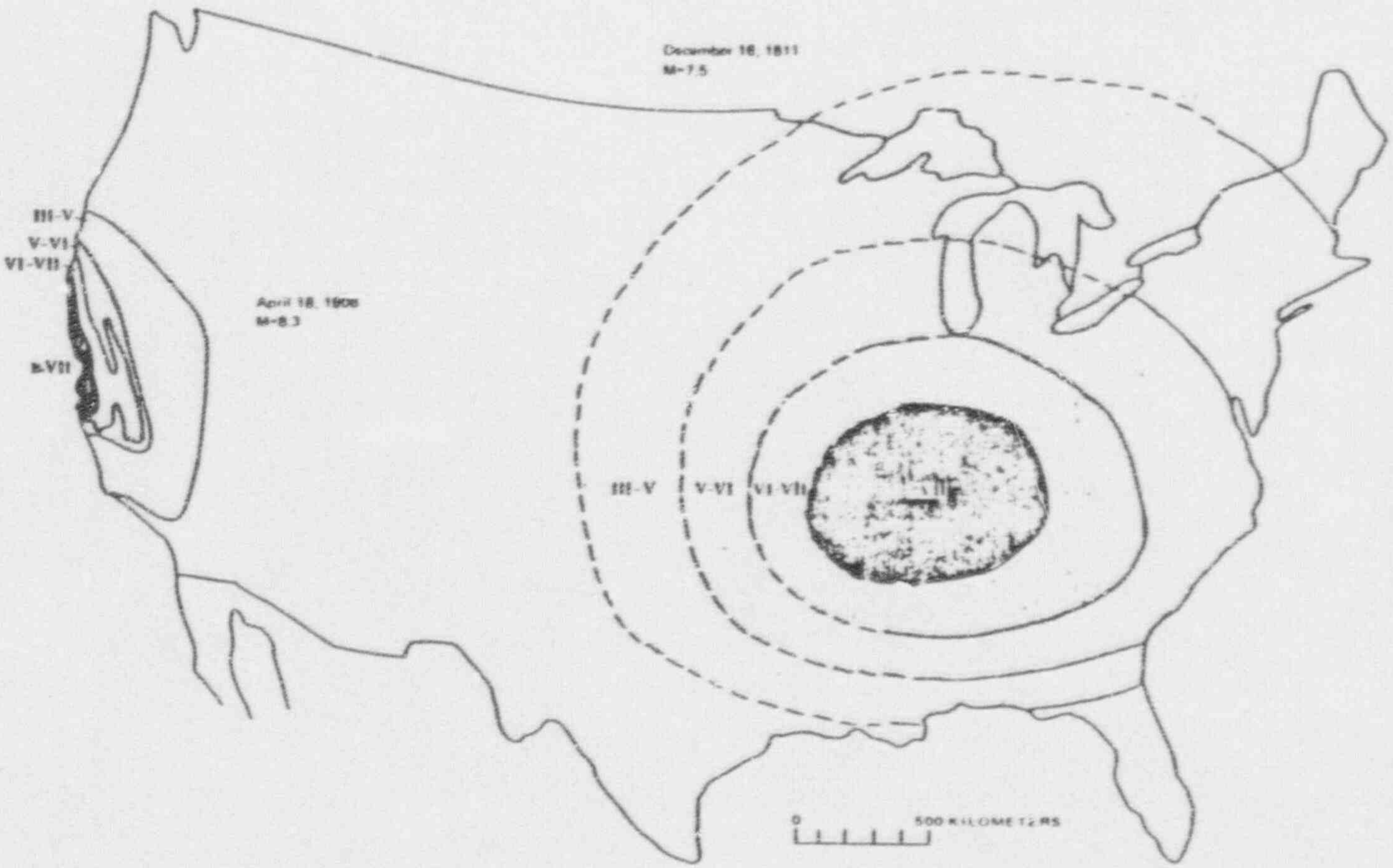
SANDIA NATIONAL LABORATORIES

THE NATURE OF EARTHQUAKES

DAMAGING EARTHQU[illegible] [illegible] [illegible]URRED

ACROSS THE ENTIRE UNITED STATES

EARTHQUAKE EFFECTS DIE OUT MUCH MORE QUICKLY IN THE WEST THAN IN THE EAST



Isoseismal contours for 1906 San Francisco and 1811 New Madrid earthquakes (modified from Nuttli, 1973b).

THE GROUND SHAKING AT A LOCATION CONSISTS OF THE SUPERPOSITION OF SEVERAL TYPES OF WAVES

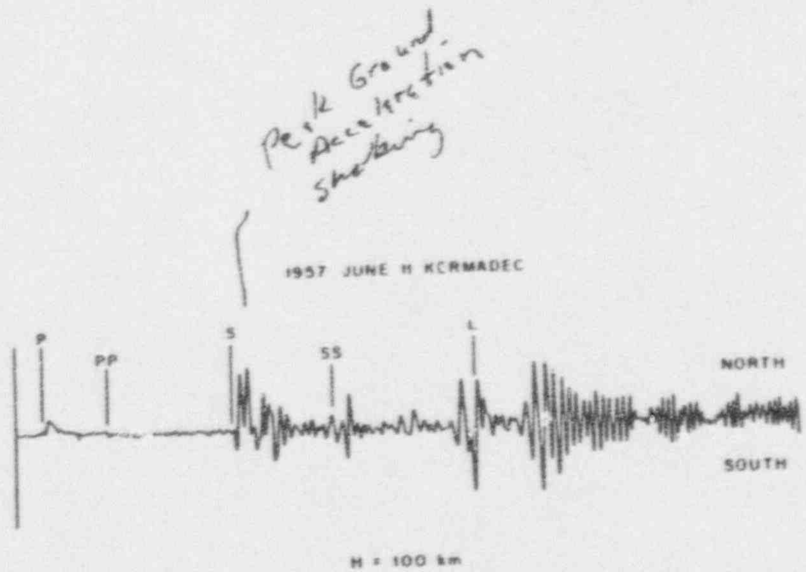
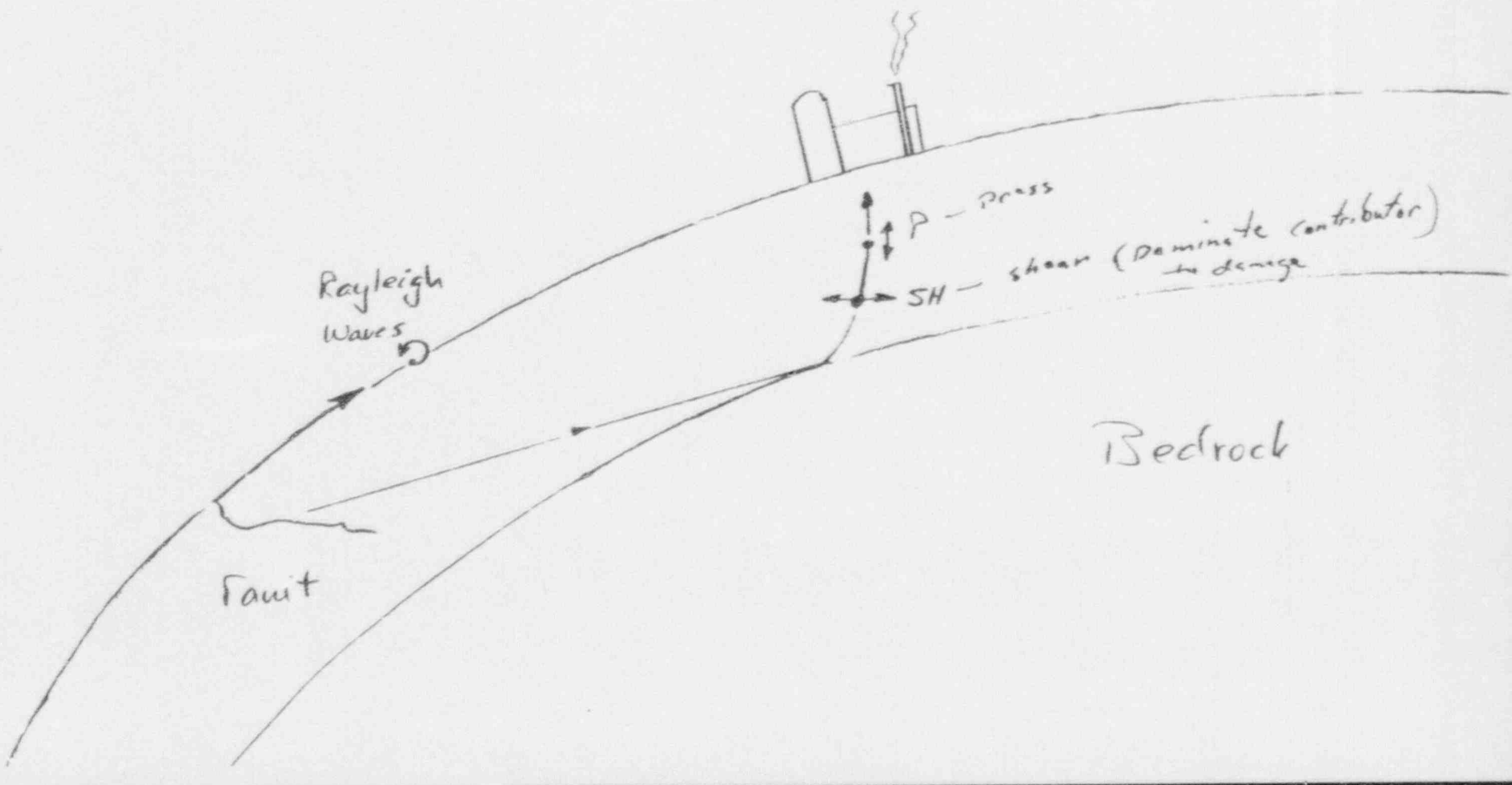


Figure 7.4. Typical earthquake accelerogram. *Adapted from* Elementary Seismology *by Charles F. Richter, W. H. Freeman and Company. Copyright © 1958.*

MOST OF THE EARTHQUAKE ENERGY ARRIVES IN P, SH, AND RAYLEIGH (SURFACE) WAVES



WAVES TRAVEL AT DIFFERENT SPEEDS, THUS HAVE DIFFERENT ARRIVAL TIMES AT A STATION

- BODY WAVES P & SH & SV ARE IN 2-10 HZ RANGE, AND USUALLY ACCOUNT FOR THE PEAK GROUND ACCELERATION (PGA).

- WAVE SPEEDS ARE:

$$V_P = \sqrt{\frac{E}{\rho}\frac{(1-\nu)}{(1+\nu)(1-2\nu)}}$$

$$V_S = \sqrt{\frac{G}{E}}$$

$$V_R = F(E,\nu)$$

- $V_P > V_S > V_R$

  SO <u>CHARACTER</u> OF WAVES DEPENDS ON DISTANCE FROM THE FAULT.

THERE ARE TWO MEASURES OF EARTHQUAKE SIZE

- MODIFIED MERCALLI INTENSITY (MM)

  THIS IS A JUDGEMENTAL SCALE BASED ON OBSERVATIONS OF DAMAGE

- RICHTER MAGNITUDE M

  DEFINED AS THE LOG OF THE TRACE AMPLITUDE OF A "STANDARD" SEISMOMETER LOCATED 100 KM FROM THE SOURCE. CORRECTION CHARTS AVAILABLE FOR DIFFERENT DISTANCES.

- ENERGY RELEASE IS RELATED TO RICHTER MAGNITUDE VIA

  $$LOG_{10} W = 11.8 + 1.5 M \text{ (ERGS)}$$

  A MEDIUM EARTHQUAKE RELEASES ENERGY EQUIVALENT TO A NUCLEAR BOMB BLAST

MODIFIED MERCALLI INTENSITY SCALE

I. Not felt. Marginal and long-period effects of large earthquakes (for details see text).

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle—CFR).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments—CFR). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations—CFR.) Frame structures, if not bolted, shifted off pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

A ROUGH CORRELATION EXISTS BETWEEN MM INTENSITY AND LOCAL ACCELERATION

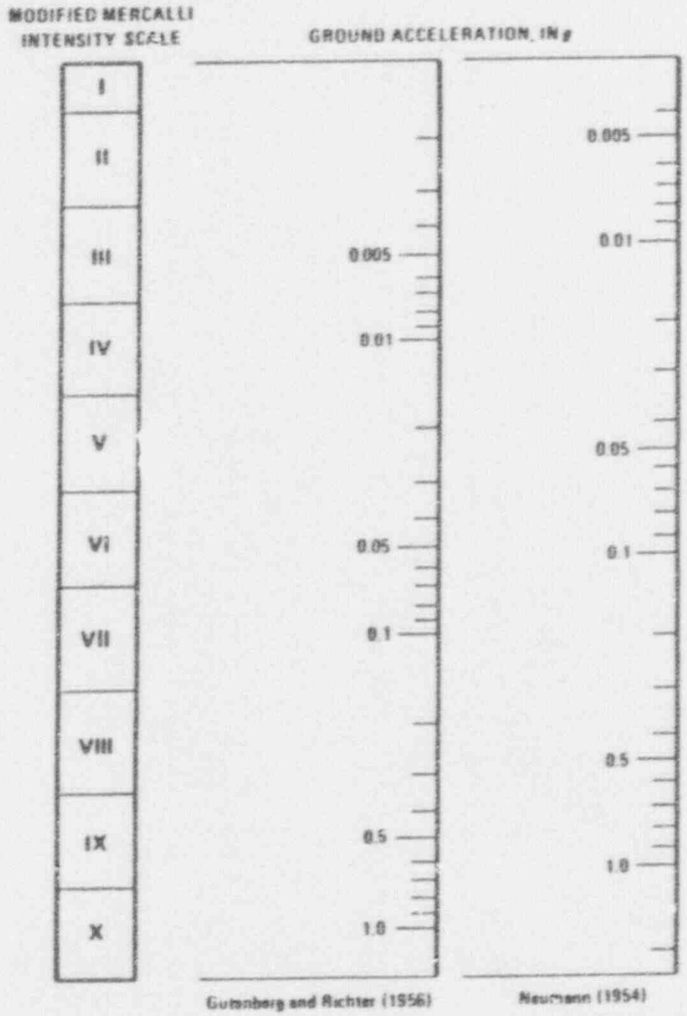
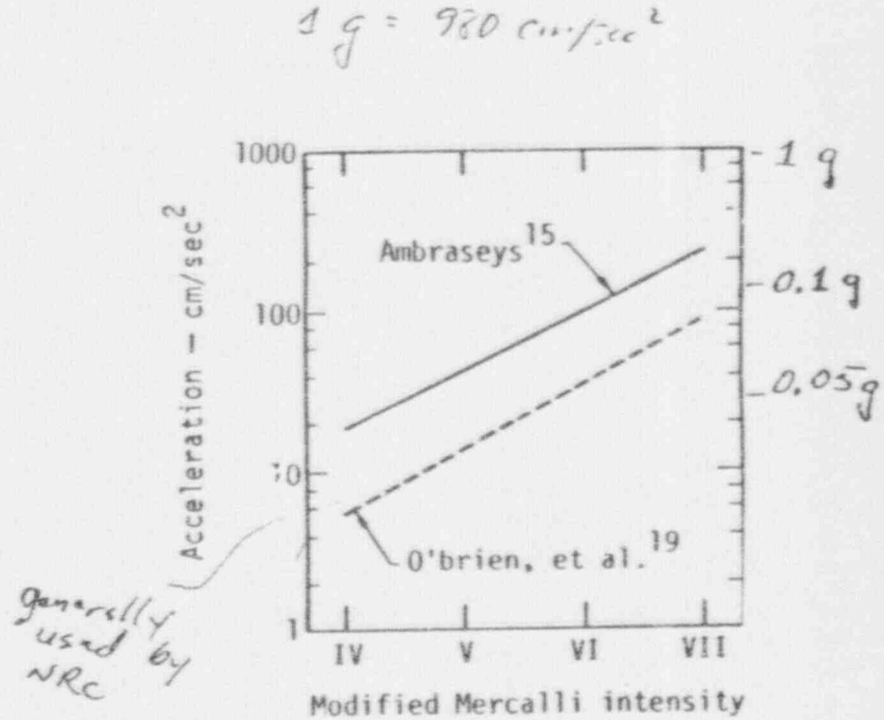


FIGURE 40—Intensity and acceleration relations proposed by Neumann (1954) and Gutenberg and Richter (1956).



THE OCCURRENCE RATE OF EARTHQUAKES IS DETERMINED FROM THE HISTORICAL RECORD FOR A GIVEN REGION

EARTHQUAKE OCCURRENCE MODELED BY THE RICHTER RELATION

$$LOG_{10} N = A - BM$$

OR

$$LOG_{10} N = A - BI$$

WHERE N = NUMBER OF EARTHQUAKES WITH MAGNITUDE GREATER THAN M (OR I)

M,I = RICHTER MAGNITUDE OR MM INTENSITY

EARTHQUAKE STUDIES HAVE BEEN PERFORMED FOR VARIOUS REGIONS OF THE UNITED STATES

Area: Nos. from fig. 3	Area: States	Recurrence relation	Earthquakes/100 yrs/100,000 km² for Modified Mercalli intensity: V	VI	VII	VIII
1	California	log $N = 3.92 - 0.54\,I$	300	84.6	23.8	6.72
2	Nevada	log $N = 3.98 - 0.56\,I$	......	......	......	......
3	Puget Sound, Wash	log $N = 3.45 - 0.62\,I$	68.0	16.3	3.92	.94
4	Montana, Idaho, Utah, Arizona (Intermountain Seismic Belt)	log $N = 3.41 - 0.56\,I$	64.4	17.7	4.99	1.35
5	Wyoming, Colorado, New Mexico	log $N = 3.66 - 0.68\,I$	32.8	6.85	1.42	.31
6	Oklahoma, North Texas	log $N = 2.10 - 0.55\,I$	13.3	3.73	1.07	.30
7	Nebraska, Kansas, Oklahoma	log $N = 1.99 - 0.49\,I$	13.0	4.20	1.35	.45
8A, B	Mississippi and St. Lawrence Valleys	log $N = 2.71 - 0.5\,I$	24.2	7.65	2.42	.76
9	East Coast	log $N = 3.02 - 0.58\,I$	12.8	3.39	.88	.23

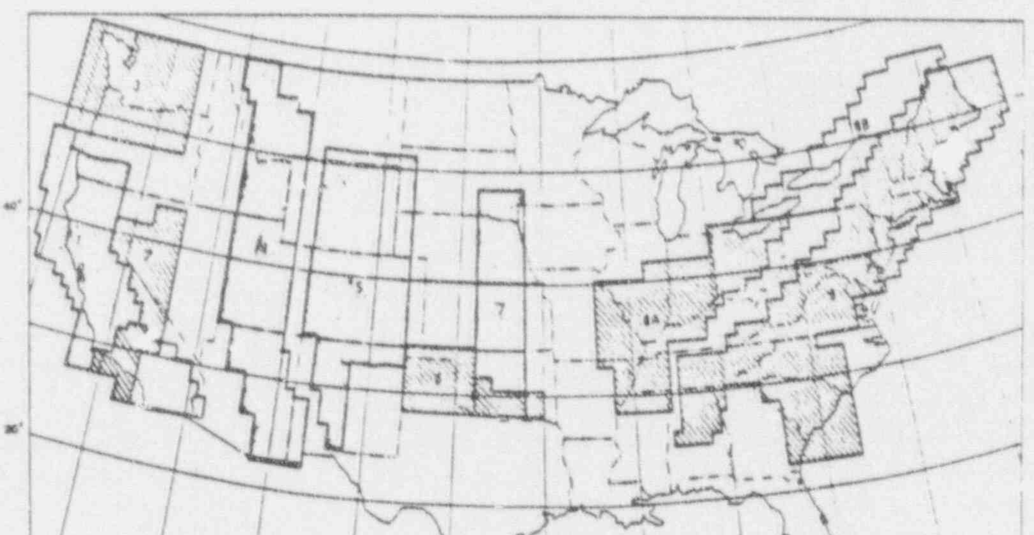


FIGURE 3.—Geographic areas of the conterminous United States where regional seismicity studies have been made (modified from Algermissen, 1969). Numbered areas are described in table 2. Shading depicts boundaries of regions.

EARTHQUAKE ACCELERATIONS DECREASE WITH DISTANCE
AWAY FROM THE SOURCE. BUT SMALL EARTHQUAKES
CAN HAVE BIG ACCELERATIONS

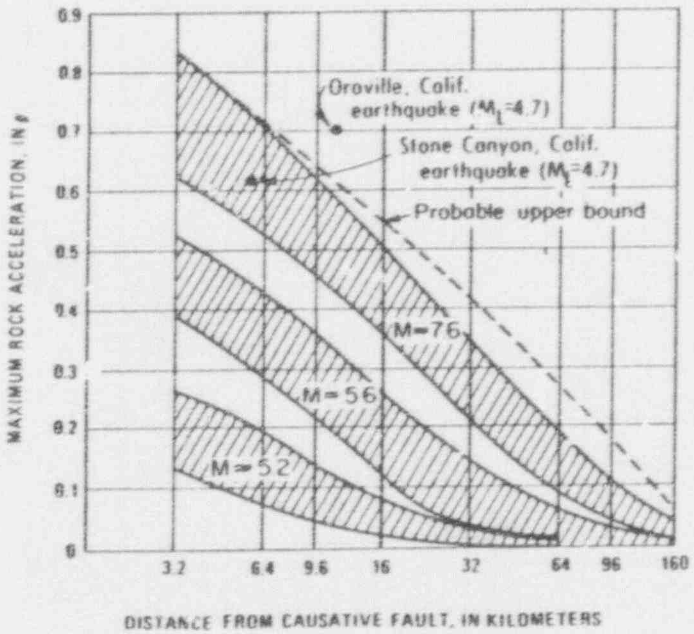


FIGURE 25 —Range of horizontal peak acceleration as a function of distance and magnitude for rock sites in the Western United States (from Schnabel and Seed, 1973).

A TYPICAL GROUND MOTION MODEL

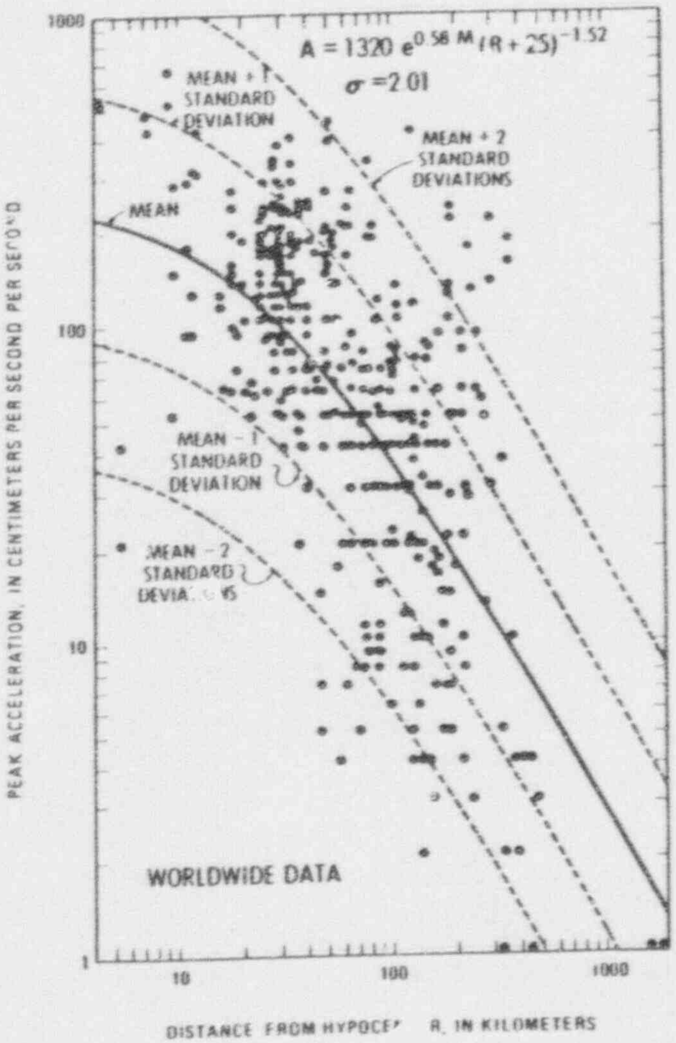
$A = 1.48M^{1.15} R^{-5/6} EXP(-\gamma R)$

$\gamma = 0.042 EXP(-0.45 M_B)$

NOTE: MAXIMUM PGA RECORDED TO DATE IS 1.6G.

CONSIDERABLE VARIATION EXISTS IF ALL DATA LUMPED TOGETHER,

SO REGIONAL ATTENUATION LAW SHOULD BE USED IF POSSIBLE.



PEAK GROUND ACCELERATION MAPS HAVE BEEN

CONSTRUCTED FOR THE UNITED STATES

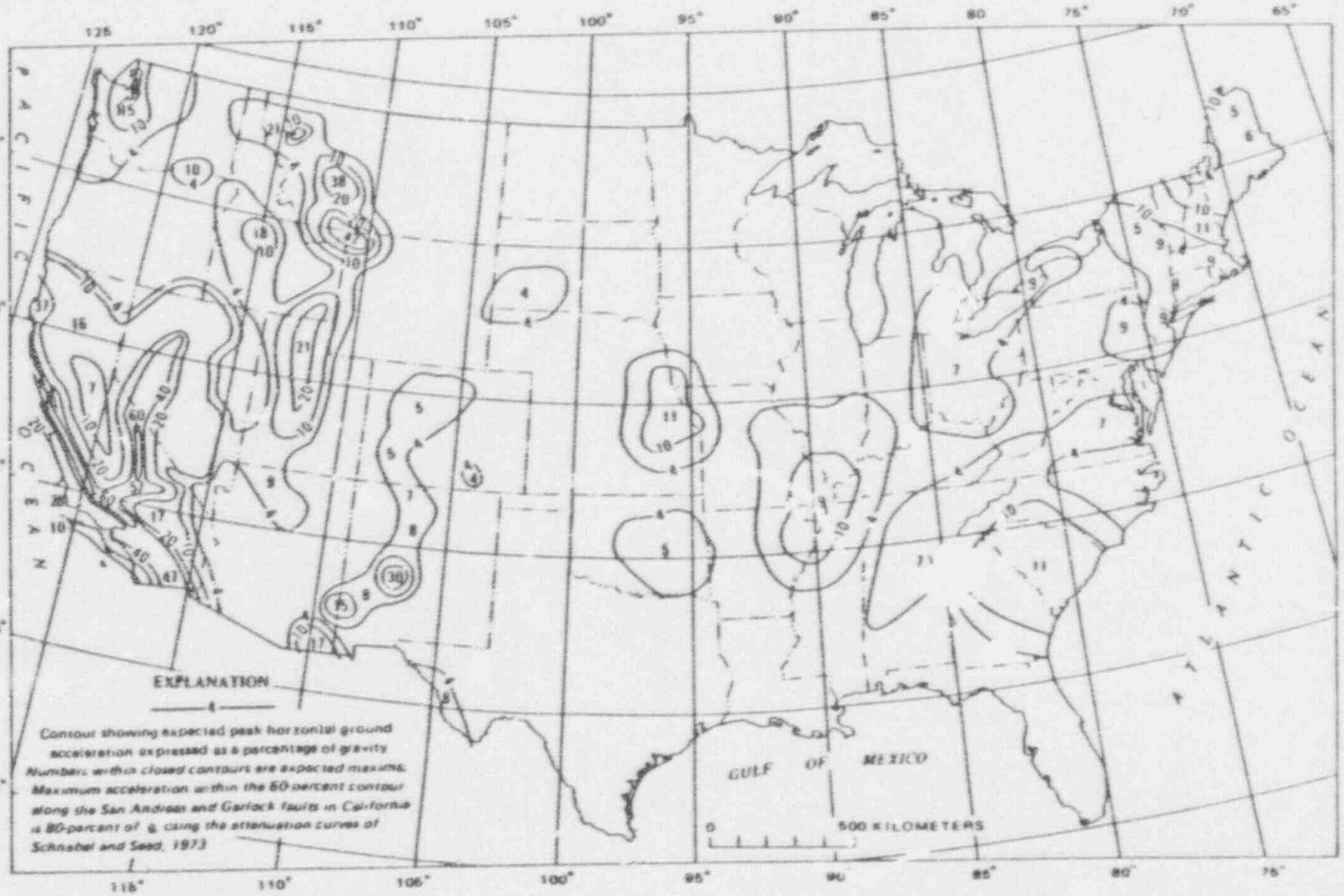
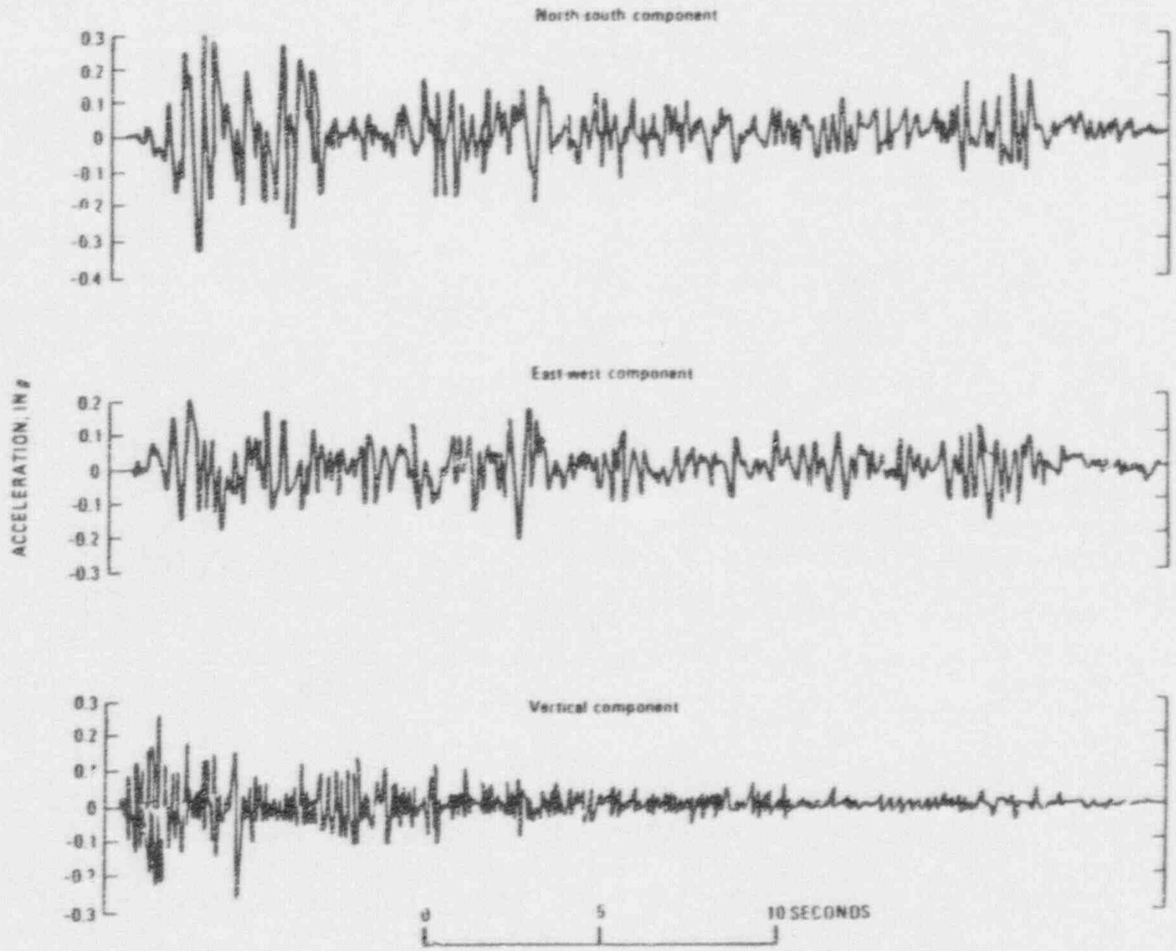


FIGURE 42.—Levels of peak horizontal ground acceleration expected at rock sites in the United States (from Algermissen and Perkins, 1976). The contoured acceleration values represent the 90-percent probability level; in other words, there is a 10-percent chance that these values will be exceeded within a 50-year period.

DAMAGING EARTHQUAKES HAVE MANY STRONG MOTION

PEAK ACCELERATION CYCLES (8-12 CYCLES TYPICALLY)

1/3 g



Vertical is 2/3 the horizontal acceleration

8 – 12 cycles of max acceleration

FIGURE 22. – Accelerogram of the 1940 Imperial Valley, Calif. earthquake recorded at El Centro, Calif.

DAMAGING EARTHQUAKES ARE BROAD BAND IN FREQUENCY, AND THUS EXCITE MANY MODES IN STRUCTURES

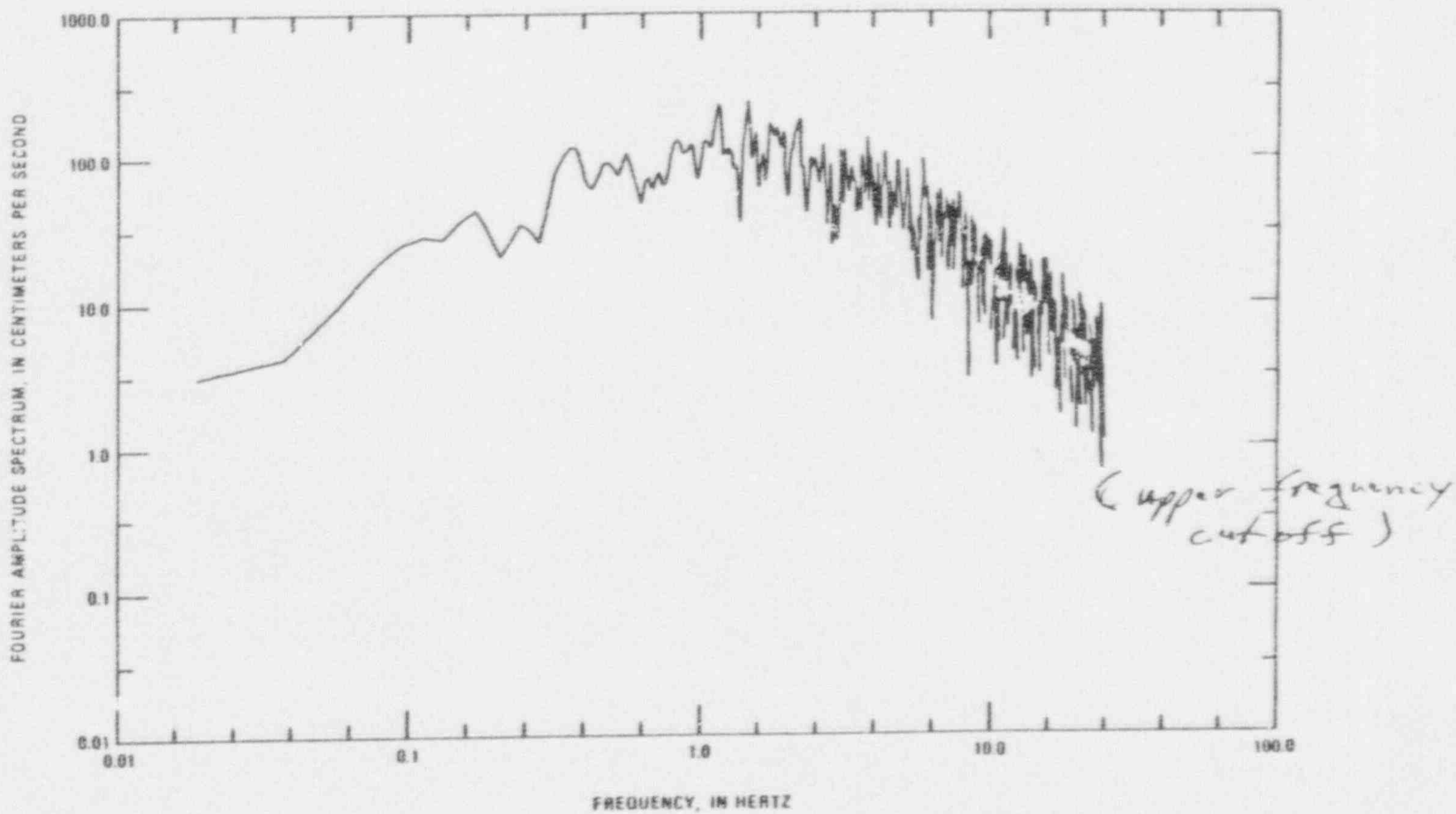
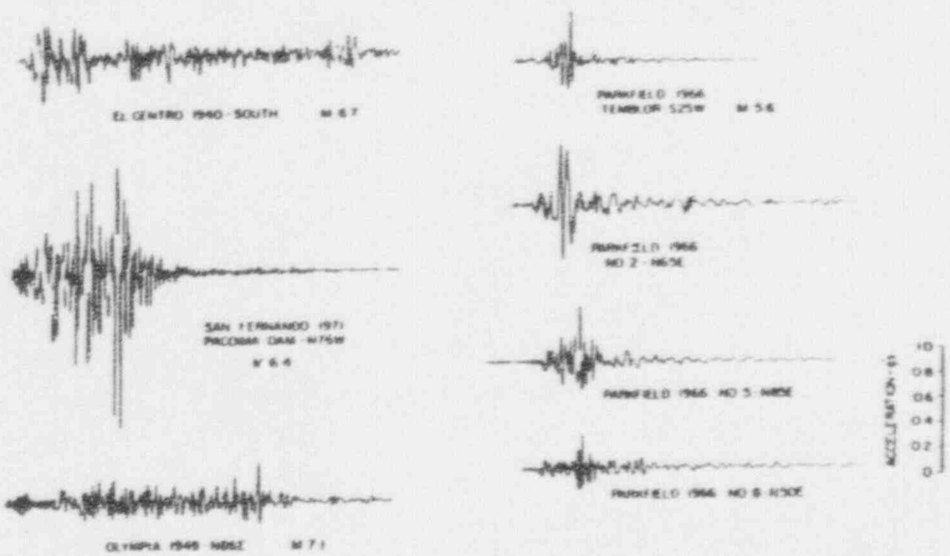


FIGURE 29.—Example of a Fourier amplitude spectrum derived from the accelerogram recorded at El Centro from the 1940 Imperial Valley, Calif., earthquake.

Peak G Accel.

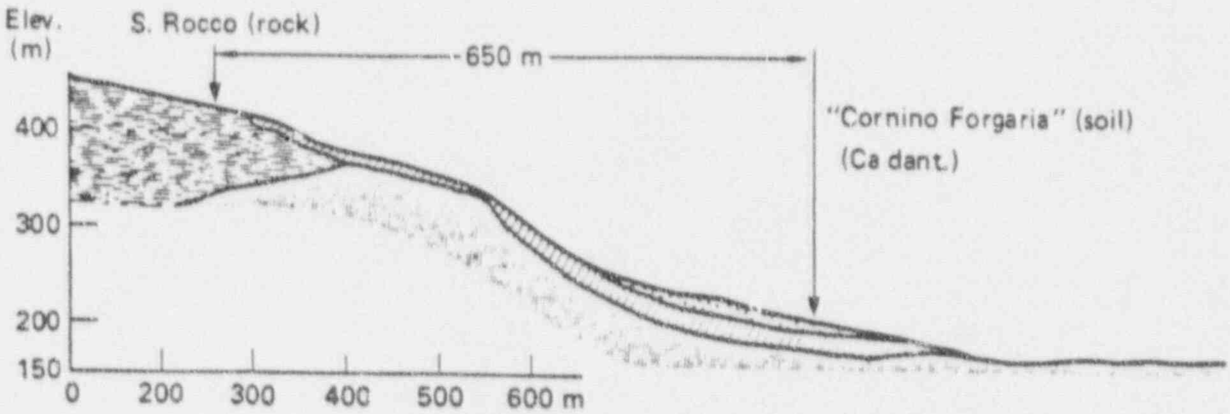
EARTHQUAKES CAN HAVE LARGE PGA, BUT NOT BE DAMAGING TO STRUCTURES. BUT COMPONENTS?

SELECTED EARTHQUAKE RECORDS (all to the same scale)

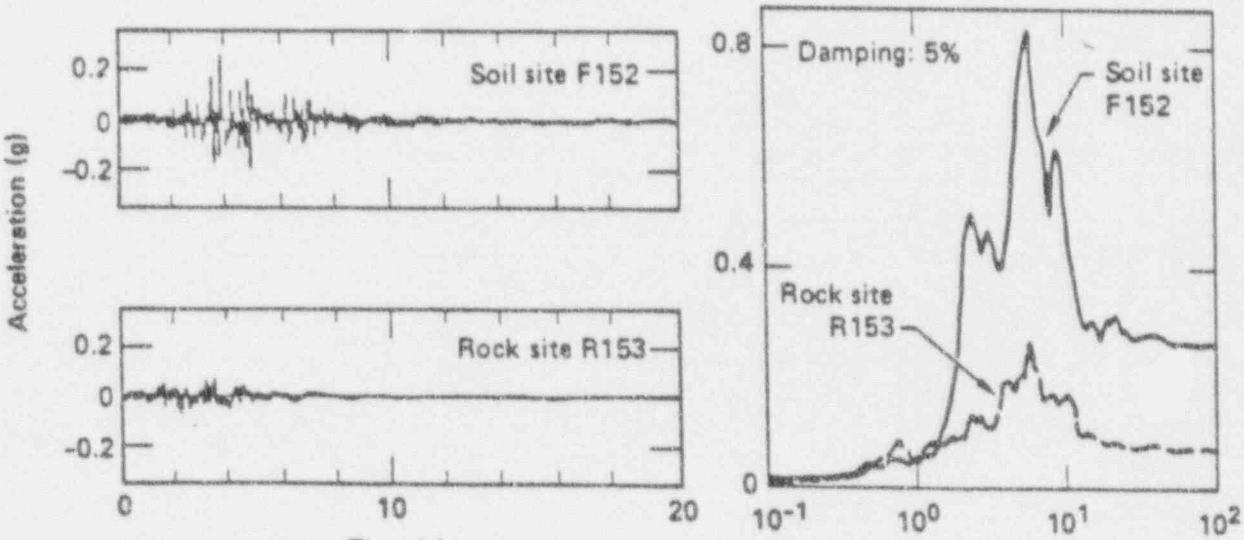


SURFACE GROUND ACCELERATIONS DEPEND ON UNDERLYING SOIL CONDITIONS

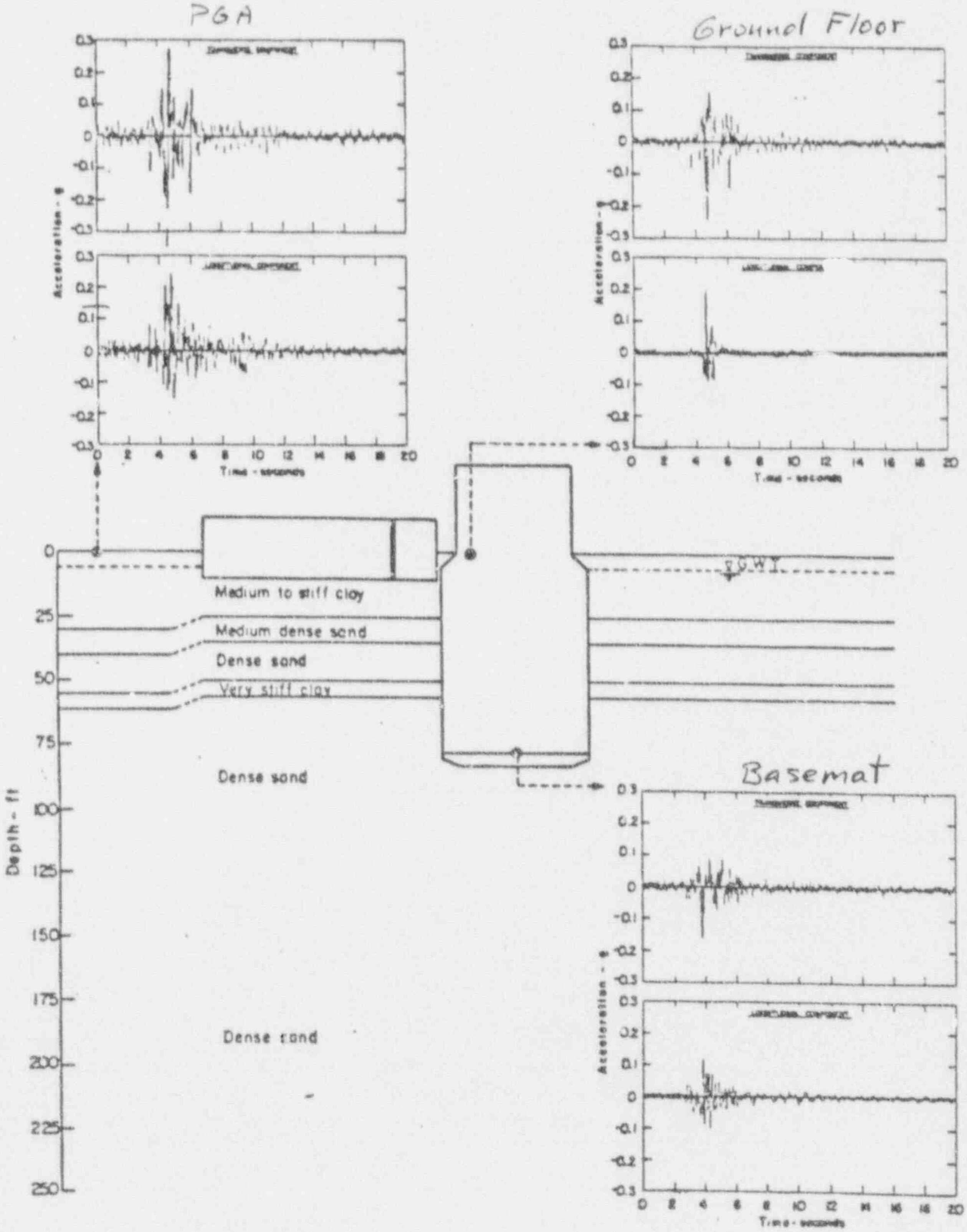
60 - 120 ft soil



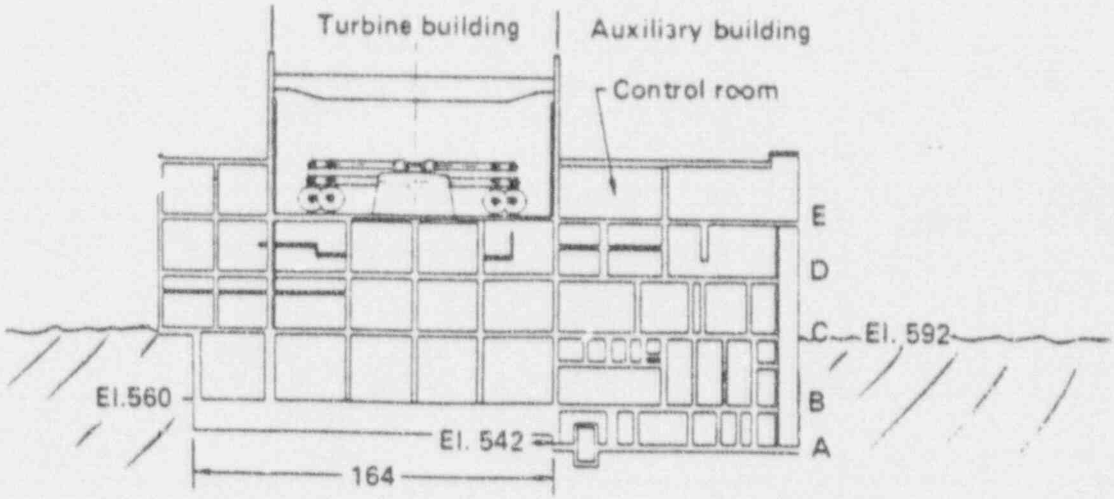
Friuli 9/15/76. Horizontal NS component (3:15:19)



IN SOIL, EARTHQUAKE ACCELERATIONS DECREASE WITH DEPTH. SO EMBEDDED STRUCTURES SEE LESS ACCELERATION



STRUCTURES AMPLIFY THE GROUND ACCELERATION, AND CHANGE THE FREQUENCY CHARACTERISTICS



All elevations and dimensions in feet

	Median Accel. (ft/s^2)	COV
A	3.0	0.195
B	3.0	0.19
C	3.2	0.23
D	3.98	0.23
E	4.0	0.26

OBSERVED COMPONENT BEHAVIOR IN EARTHQUAKES

MODERN POWER PLANT EQUIPMENT HAS PERFORMED WELL IN EARTHQUAKES IF PROPERLY ANCHORED

- SQUG & SSRAP HAVE REVIEWED EARTHQUAKE EXPERIENCE
- ASSESSMENT DERIVED GROUND MOTION SPECTRA FOR WHICH EIGHT TYPES OF EQUIPMENT WOULD REMAIN FUNCTIONAL

MCCS	MOVS
480 V SWITCHGEAR	AOVS
4 KV SWITCHGEAR	HORIZONTAL PUMPS & MOTORS
SUBSTATION TRANSFORMERS	VERTICAL PUMPS & MOTORS

- IT IS PROPOSED (A-46) THAT IF THE DESIGN GROUND SPECTRA IS BELOW THE DERIVED BOUNDING SPECTRA, SEISMIC QUALIFICATION IS <u>NOT</u> REQUIRED.

— Below .3g these items function (East coast sites do not have to test

contrary

INADEQUATE ANCHORAGE CAUSES MOST OBSERVED DAMAGE

- SWITCHGEAR AND MCSs TIP
- FLAT BOTTOM TANKS SLIDE, SHEAR PIPES
- BATTERY RACKS PULL-OUT ANCHOR BOLTS
- TRANSFORMERS SLIDE AND SHEAR CABLES
- SUSPENDED CEILINGS COLLAPSE
- CABLES IN YARD (FLEXIBLE BUS CONDUCTORS) FAIL DUE TO INADEQUATE SLACK

CERAMIC INSULATORS IN YARD CRACK AND FAIL AT RELATIVELY LOW-LEVEL EARTHQUAKES

- MEDIUM FAILURE LEVEL 0.25 G, BUT FAILURES HAVE OCCURRED AS LOW AS 0.11 G.
- THIS MEANS LOSS OF OFFSITE POWER DURING AN EARTHQUAKE OF SSE LEVEL IS MOST LIKELY

CIRCUIT BREAKERS TRIP AND RELAYS CHATTER DURING EARTHQUAKES

- STRUCTURALLY, NO PERMANENT DAMAGE, AND BREAKERS CAN BE MANUALLY RESET FOLLOWING QUAKE
- BUT, IF TRIPPED BREAKER CANNOT EASILY BE LOCATED, OR IF RELAY CHATTER CAUSES A "LOCKING" CIRCUIT TO CHANGE STATE, THESE MALFUNCTIONS CAN HAVE SAFETY IMPLICATIONS.
- VIRTUALLY, ALL SWITCHGEAR, MCCs, BATTERY CHARGES AND INVERTORS CONTAIN RELAYS AND CIRCUIT BREAKERS!

FLAT BOTTOM VERTICAL STORAGE TANKS ARE VULNERABLE
TO GROUND SHAKING EVEN IF ANCHORED

- THESE INCLUDE TYPICAL RWST, CST AND DEMINERALIZED WATER STORAGE TANKS.
- TYPICALLY, 20-40 FT OD BY 24-60 FT HIGH
- ANCHOR BOLTS YIELD, AND GET PLASTIC BUCKLING (ELEPHANT'S FOOT) AT BOTTOM OF ONE SIDE.

REQUIREMENTS FOR SEISMIC EQUIPMENT QUALIFICATION
IN US NUCLEAR POWER PLANTS

THE LEGAL REQUIREMENT FOR SEISMIC EQUIPMENT QUALIFICATION IS

- GENERAL DESIGN CRITERIA 1, 2, 4, AND 23 OF APPENDIX A TO 10CFR50
- APPENDIX B TO 10CFR50

TECHNICAL GUIDANCE AND APPROVED QUALIFICATION METHODS ARE PRESCRIBED IN

- REG. GUIDE 1.100 — SEISMIC QUALIFICATION OF ELECTRIC EQUIPMENT FOR NUCLEAR POWER PLANTS
- STD. REVIEW PLAN 3.10 — SEISMIC AND DYNAMIC QUALIFICATION OF MECHANICAL AND ELECTRICAL EQUIPMENT
- IEEE 344-1975 — IEEE RECOMMENDED PRACTICES FOR SEISMIC QUALIFICATION OF CLASS 1E EQUIPMENT FOR NUCLEAR POWER GENERATING STATIONS
- IEEE STANDARDS FOR VARIOUS COMPONENTS, E.G.,
  - IEEE 382-1980 (VALVE ACTUATORS)
  - IEEE 387-1977 (DIESEL GENERATORS)
  - ETC.

TWO EARTHQUAKE LEVELS ARE PRESCRIBED AT EACH SITE FOR DESIGN AND QUALIFICATION PURPOSES

- THE OPERATING BASIS EARTHQUAKE (OBE)

  THE MAXIMUM EARTHQUAKE TO BE REASONABLY EXPECTED DURING THE LIFE OF THE PLANT. PLANT SHOULD BE CAPABLE OF CONTINUED OPERATION FOLLOWING AN OBE. One you would expect within 50 yrs.

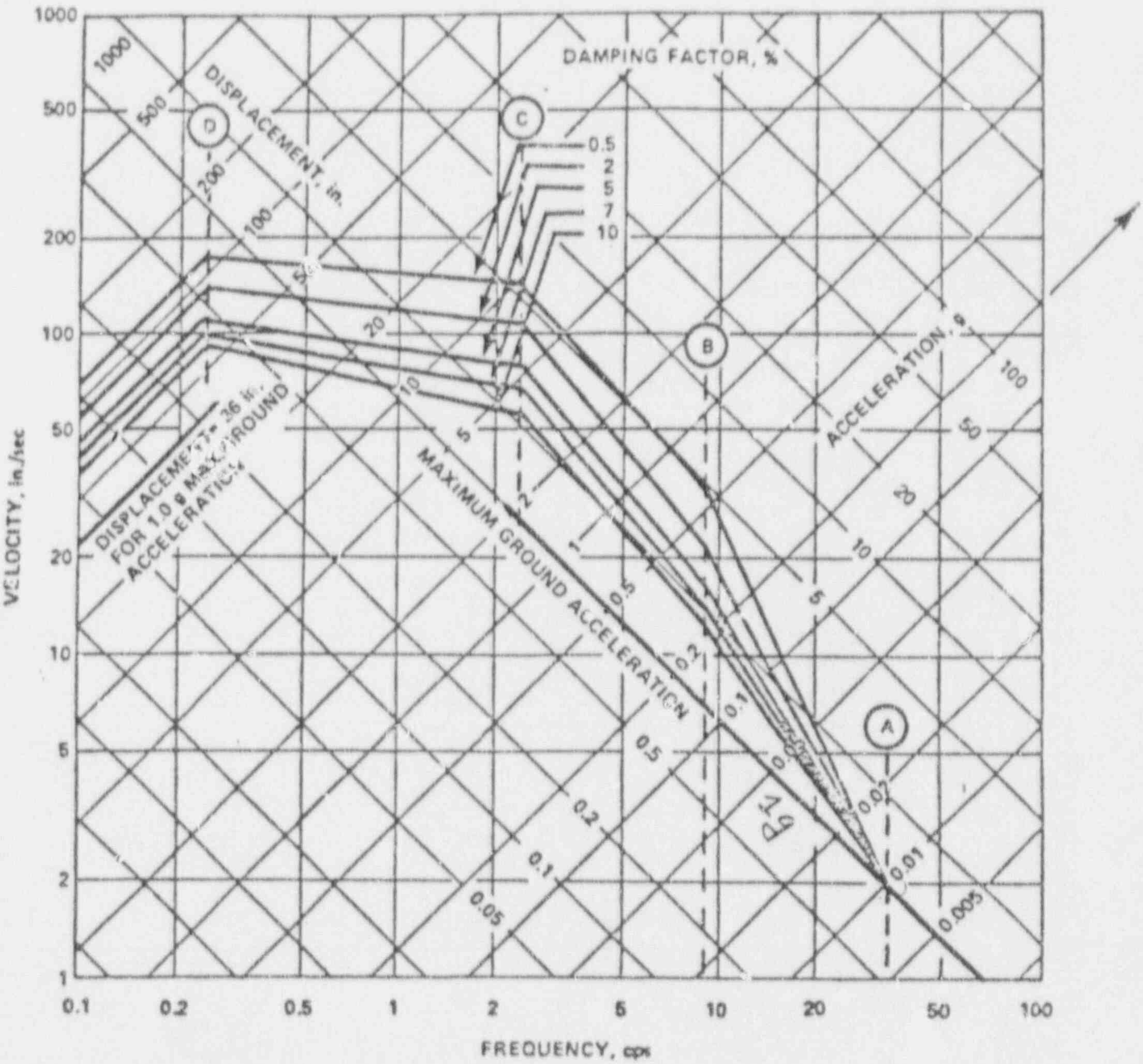
- THE SAFE SHUTDOWN EARTHQUAKE

  THE MAXIMUM PLAUSIBLE EARTHQUAKE AT THE SITE. DAMAGE EXPECTED, BUT COMPONENTS REQUIRED TO BRING PLANT TO SAFE SHUTDOWN MUST FUNCTION.

THE OBE AND SSE ARE DETERMINISTIC DEFINITIONS

- DERIVED FROM:
  - LOCAL SEISMIC HISTORICAL RECORD
  - LOCAL GEOLOGICAL FEATURES (SIZE AND NUMBER OF FAULTS)
  - DETERMINATION OF LEVELS AND GROUND MOTION FROM POTENTIAL EARTHQUAKES
  - SITE-MATCHED RECORDED EARTHQUAKES
  - LOCAL SITE CHARACTERISTICS
  - MM INTENSITY VS. ACCELERATION CORRELATION
- THE OBE AND SSE ARE SPECIFIED BY A VALUE OF PEAK GROUND ACCELERATION AND A SPECTRA:
  - REG. GUIDE 1.60 PROVIDES AN ALLOWABLE SPECTRA, BUT SITE SPECIFIC SPECTRA MAY BE DEVELOPED

THE RG. 1.60 SPECTRA WAS DERIVED FROM AN ENSEMBLE OF RECORDED EARTHQUAKE TIME HISTORIES (BOTH ROCK AND SOIL) AND IS AN 84% CONFIDENCE LEVEL SPECTRA



HORIZONTAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

TYPICAL OBE IS HALF THE SSE, AND MINIMUM ALLOWABLE SSE IS 0.10 G

WEST COAST		EAST COAST	
TROJAN	0.25 G	ZION	0.18 G
DIABLO CANYON	0.75 G	QUAD CITIES	0.24 G
SAN ONOFRE	0.67 G	TURKEY POINT	0.15 G
RANCHO SECO	0.25 G	POINT BEACH	0.12 G
HUMBOLT BAY	0.50 G	INDIAN POINT	0.15 G
		ST. LUCIE	0.10 G

APPROACHES TO SEISMIC QUALIFICATION

SEISMIC QUALIFICATION CAN BE ACHIEVED IN THREE WAYS

- ANALYSIS

  USED FOR "SIMPLE" STRUCTURES WITH STRUCTURAL FAILURE MODES - USUALLY THOSE TOO BIG TO TEST (E.G., STEAM GENERATOR).

- COMBINED TESTING AND ANALYSIS

  RESPONSE TO A FORCED OSCILLATION YIELDS MASS AND STIFFNESS PROPERTIES, AND DAMPING CAN BE MEASURED. THEN DYNAMIC ANALYSIS IS USED TO CALCULATE COMPONENT RESPONSE TO DESIGN EARTHQUAKES.

- TESTING

  THE BEST. USUALLY ESSENTIAL FOR FUNCTIONAL (RATHER THAN STRUCTURAL) FAILURE MODES.

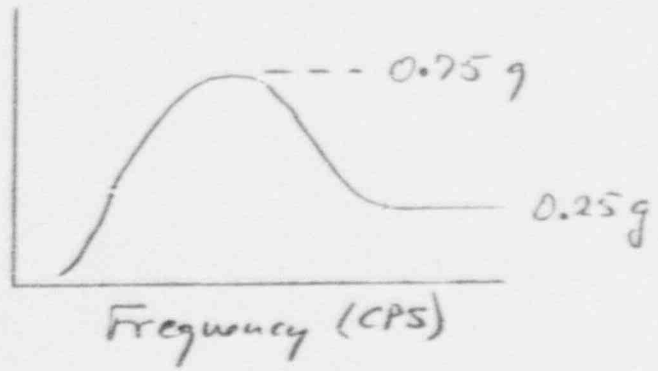
FOUR METHODS COMMONLY USED FOR ANALYSIS

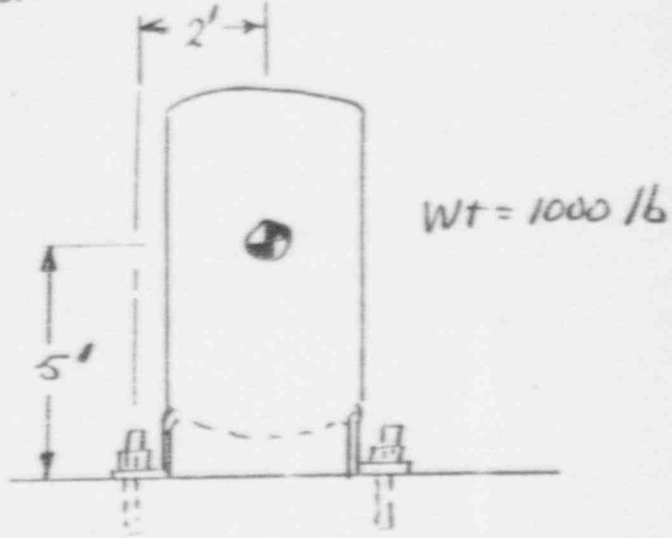
- EQUIVALENT STATIC ANALYSIS
- RESPONSE SPECTRUM ANALYSIS } MOST COMMON TODAY
- TIME HISTORY ANALYSIS } MOST COMMON TODAY
- POWER SPECTRAL DENSITY ANALYSIS

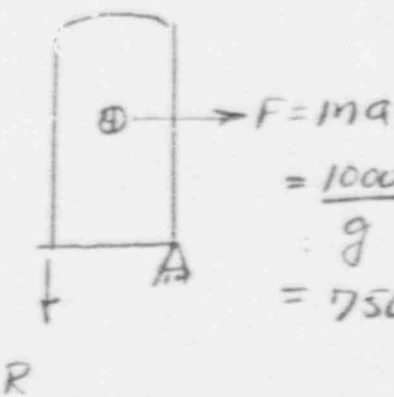
Example   Equivilent Static Analysis

Skirt Mounted Tank

Assume SSE = 0.25 g and spectra







$F = ma$

$= \frac{1000\,lb}{g}(0.75g)$

$= 750$ lbs

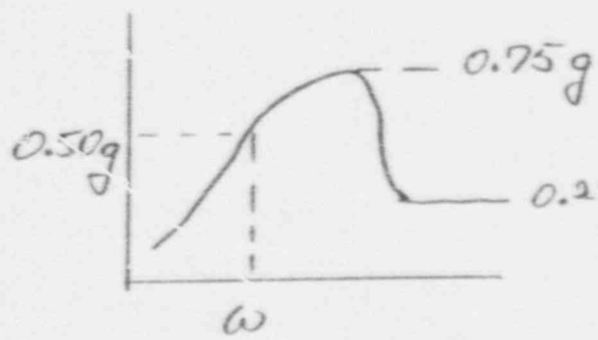
Moment Equilibrium

$2R = 5F = 3750$ Ft-lbs

$R = 1875$ lbs

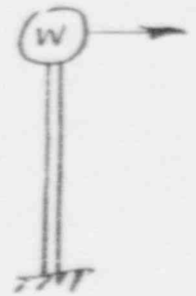
Allowable bolt pullout load is 2600 lbs

Example — Response Spectrum Analysis
Skirt Mounted Tank



Compute spring constant of skirt, k

Compute natural frequency $\omega = \sqrt{\frac{k}{M}}$



$F = ma$

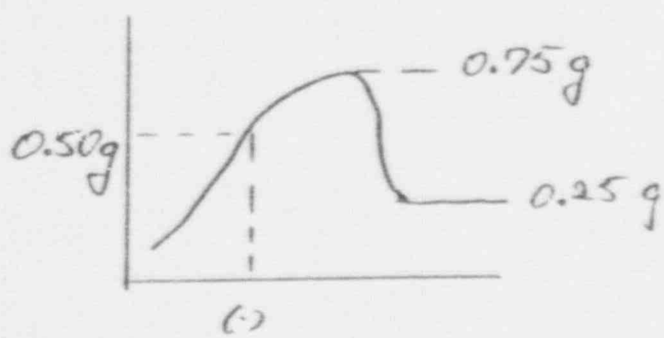
$= \frac{1000}{g}(0.5g)$

$= 500$ lbs

$2k = 5F = 2500$ Ft-lb

$k = 1250$ lbs

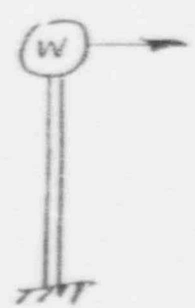
<u>Example</u> Response Spectrum Analysis
Skirt Mounted Tank



W = 1000 lb

Compute spring constant of skirt, k

Compute natural frequency $\omega = \sqrt{\frac{k}{M}}$



$F = ma$

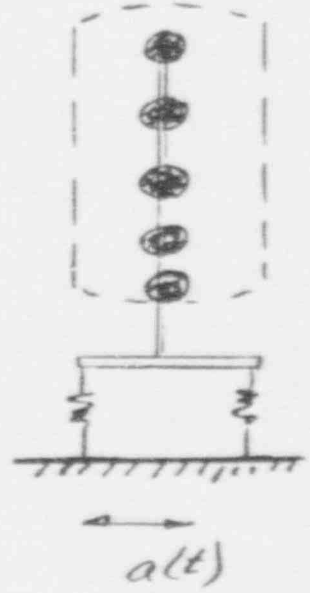
$= \frac{1000}{g}(0.5g)$

$= 500$ lbs

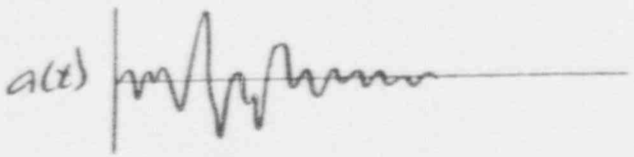
$2k = 5F = 2500$ Ft-lb

$k = 1250$ lbs

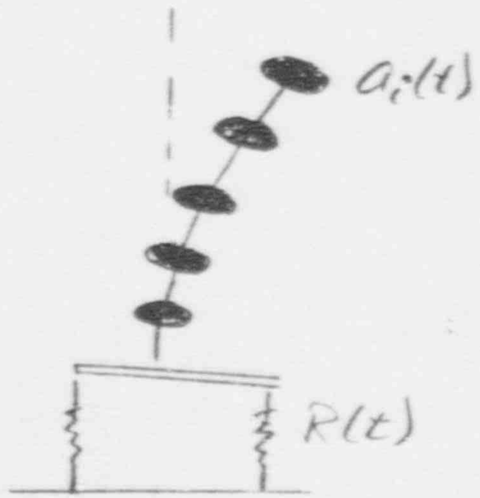
Example Time History Analysis
Skirt Mounted Tank



Usually a multi-node lumped mass model is developed, interconnected with weightless springs. A base acceleration time history is prescribed.



The acceleration of each mass is obtained and anchor forces as a [illegible] ction of time.

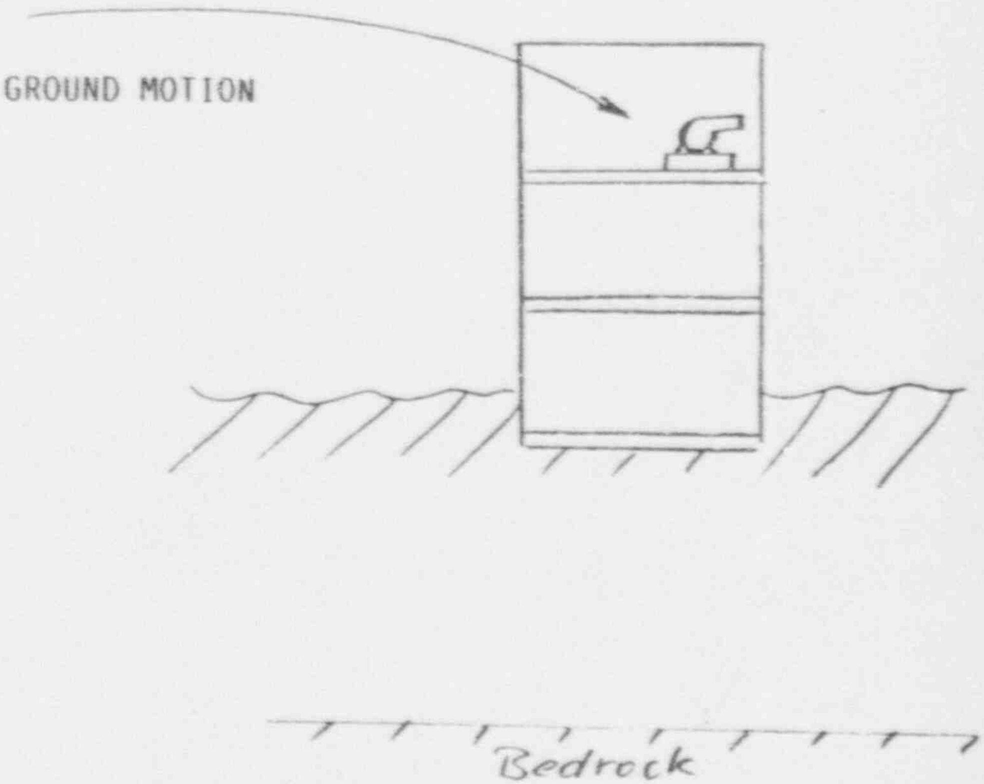


SPECIFICATION OF MOTION FOR QUALIFICATION PURPOSES

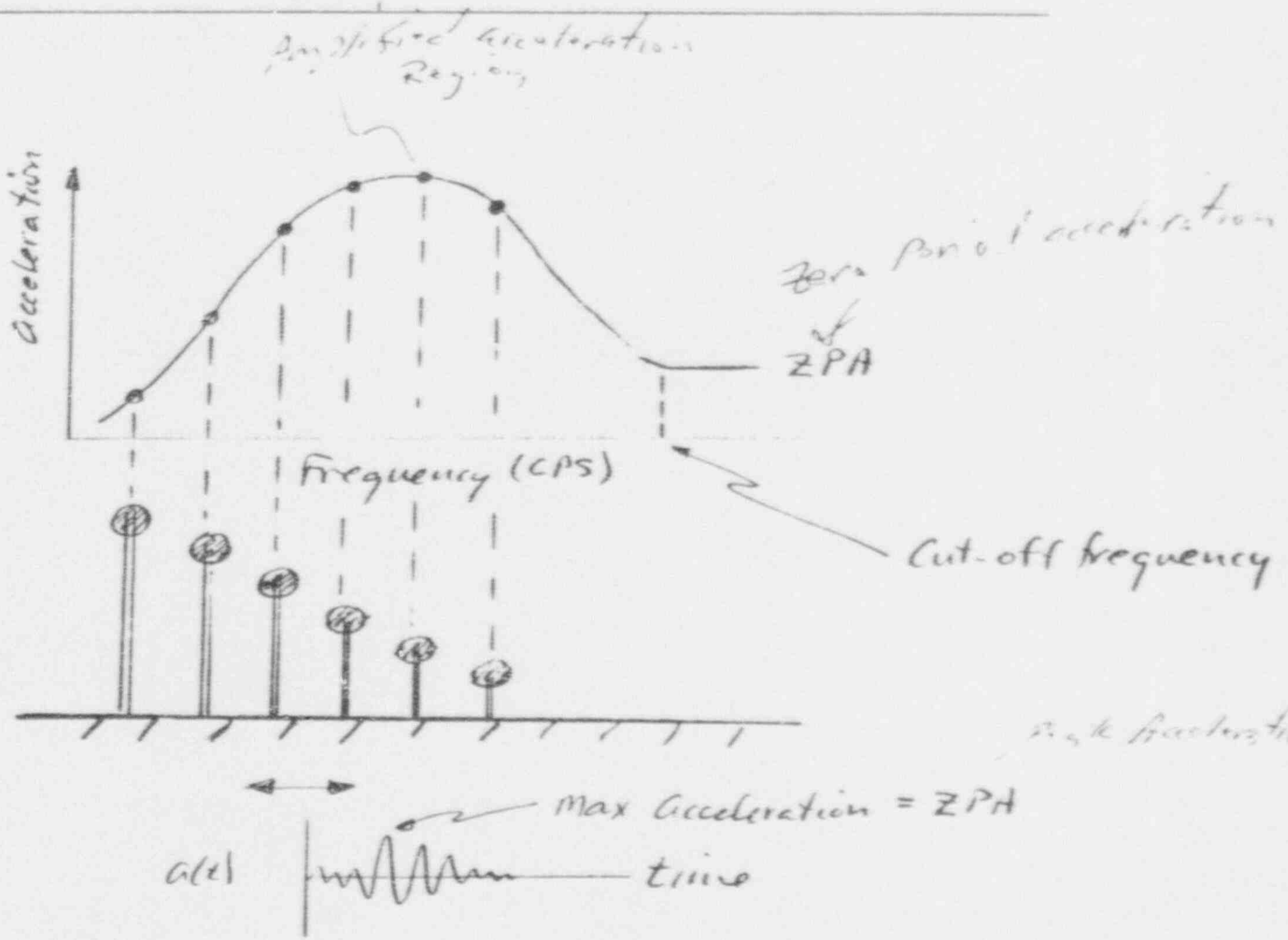
MOTION IS SPECIFIED IN TERMS OF A RESPONSE SPECTRA

THE RESPONSE SPECTRA MUST REFLECT

- ACTUAL LOCATION IN BUILDING
- AMPLIFICATION AND FILTERING OF GROUND MOTION BY BUILDING
- EMBEDMENT
- SOIL-STRUCTURE INTERACTION
- DESIGN EARTHQUAKE



A RESPONSE SPECTRA IS THE LOCUS OF ACCFLERATIONS EXPERI NCED BY FAMILY OF SINGLE DEGREE OF FREEDOM OSCILLATORS EXCITED BY A GIVEN BASE ACCELERATION, WITH A GIVEN DAMPING



SPECTRA ARE VERY SENSITIVE TO DAMPING LEVEL

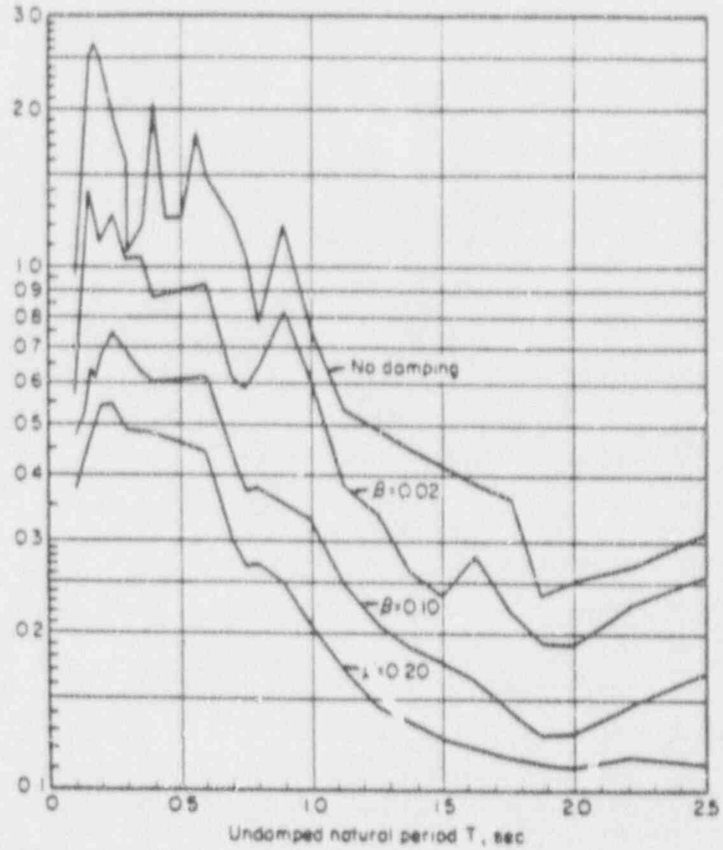


Fig. 1-5. Acceleration spectra for elastic systems, 1940 El Centro earthquake.

NOTES ON RESPONSE SPECTRA

- IT DOES CHARACTERIZE SEVERITY AND FREQUENCY CONTENT OF LOCAL (FLOOR SLAB) EXCITATION.
- IT DOES SPECIFY WHEN A COMPONENT CAN BE CONSIDERED RIGID.
- IT DOES <u>NOT</u> SUPPLY THE TIME HISTORY THAT PRODUCED THE SPECTRA. GIVEN A SPECTRA, <u>MANY</u> TIME HISTORIES CAN BE GENERATED WHICH CLOSELY MATCH THE SAME SPECTRA.
- IT DOES <u>NOT</u> SPECIFY THE DURATION OF MOTION OF THE TIME HISTORY THAT PRODUCED THE SPECTRA.

RESPONSE SPECTRA ARE OFTEN GIVEN AS "TRI-PARTITE" PLOTS

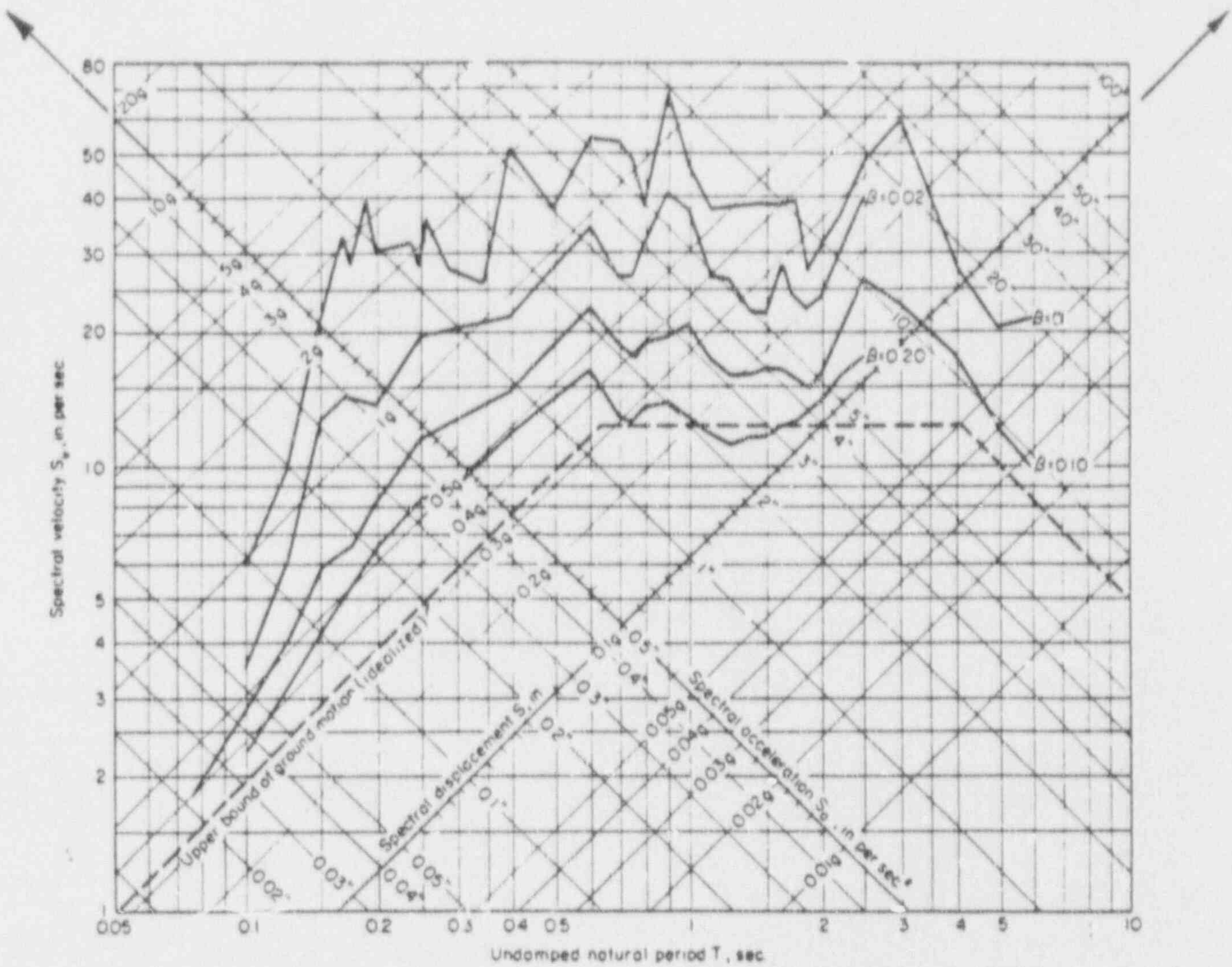


Fig. 1-6. Response spectra for elastic systems, 1940 El Centro earthquake.

SEISMIC TESTING

IN GENERAL, THERE ARE THREE TYPES OF QUALIFICATION TESTS

- PROOF TESTS

  TESTING TO A SPECIFIC LOCATION SPECTRUM FOR A SPECIFIC APPLICATION.

- GENERIC TESTS

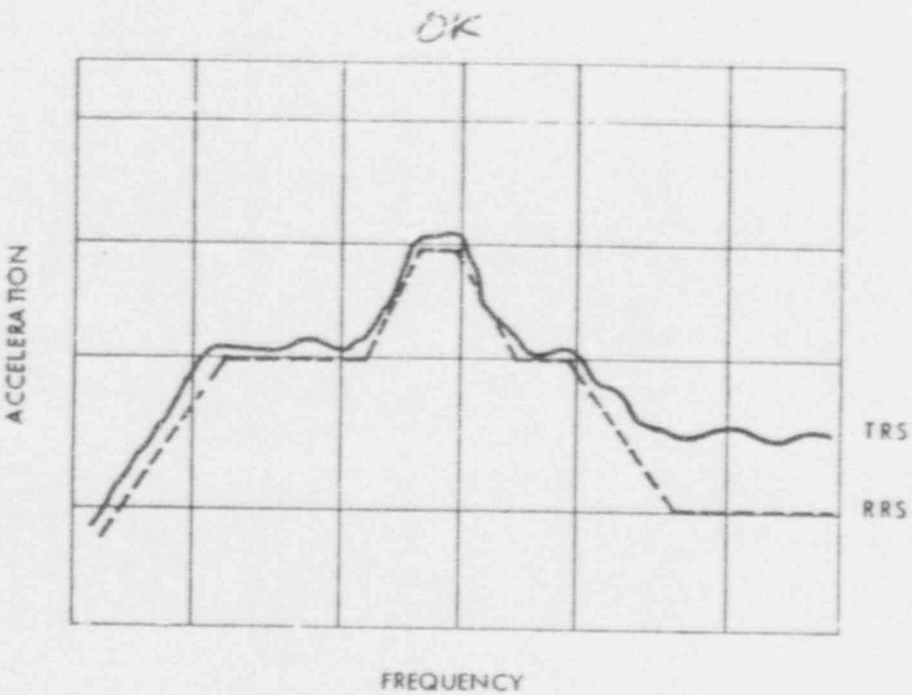
  THE RRS IS CHOSEN TO ENVELOPE SPECTRA FOR A VARIETY OF LOCATIONS. MORE HARSH THAN PROOF TEST.

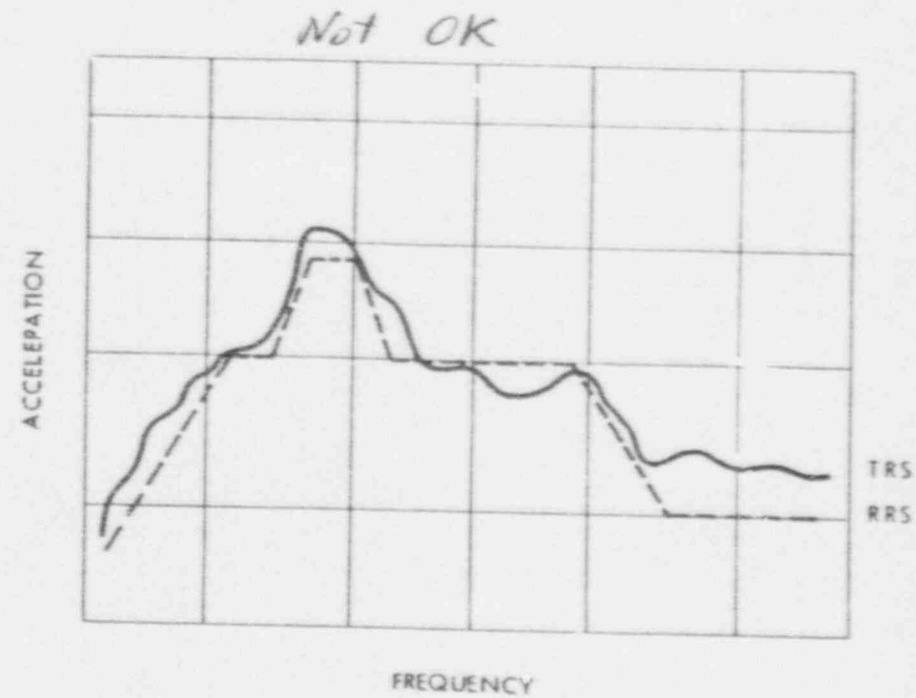
- FRAGILITY TESTS

  THE EQUIPMENT IS TESTED UNTIL ITS ULTIMATE FUNCTIONAL CAPACITY IS DETERMINED.

TO QUALIFY EQUIPMENT, THE TEST RESPONSE SPECTRUM (TRS) MUST ENVELOP THE REQUIRED RESPONSE SPECTRUM (RRS)

- THE TRS IS THE SPECTRA OF THE SHAKE TABLE MOTION.
- THE DAMPING OF THE TRS, RRS AND THE ACTUAL EQUIPMENT DAMPING SHALL BE THE SAME.





IEEE-344 CRITERIA FOR ACCEPTANCE OF TEST RESPONSE SPECTRA

FOR ANY WAVEFORM EMPLOYED, THE SHAKE TABLE MOTION MUST BE ADJUSTED SO THAT:

1. THE TRS ENVELOPS THE RRS OVER THE FREQUENCY RANGE OF INTEREST.

2. TRS SHOULD BE COMPUTED WITH A DAMPING VALUE EQUAL TO THAT OF THE RRS.

3. THE SHAKE TABLE MAXIMUM PEAK ACCELERATION SHOULD EQUAL OR EXCEED THE ZPA OF THE RRS.

4. THE TOTAL TEST DURATION AND NUMBER OF EQUIVALENT MAXIMUM PEAK CYCLES SHOULD BE PER THE DESIGN SPECIFICATION.

CONSIDERATIONS IN SPECIFYING AND REVIEWING SEISMIC TESTING

- NORMAL   DING AND ENVIRONMENT DURING TEST
- MONITORING OF EQUIPMENT FUNCTION & ACCEPTANCE CRITERIA
- MOUNTING ON TEST TABLE
- MONITORING OF TRS AND EQUIPMENT ACCELERATION
- EXPLORATORY TESTS
- TESTING SEQUENCE
- SINGLE VS. BIAXIAL VS. TRIAXIAL TESTS
- CHOICE OF WAVEFORM AND DURATION TO MEET RRS
- REQUIRED DOCUMENTATION

NORMAL LOADING AND ENVIRONMENT DURING TEST

- IEEE-344 REQUIRES TESTS TO BE PERFORMED WITH EQUIPMENT SUBJECT TO NORMAL OPERATING CONDITIONS (PRESSURE, ELECTRICAL, MECHANICAL & THERMAL LOADS, ETC.)
- GUIDELINES FOR LOADS AND ENVIRONMENT FOR CLASS 1E ELECTRICAL EQUIPMENT GIVEN IN IEEE-323-1974.
- IF NOT INCLUDED IN TEST, ABSENCE MUST BE JUSTIFIED.

MONITORING OF EQUIPMENT FUNCTION AND ACCEPTANCE CRITERIA

- OPERATION BEFORE AND AFTER TEST MUST BE DEMONSTRATED
- OPERATION USUALLY REQUIRED DURING TEST IF POSSIBLE
- EXPLICIT PROCEDURES NEEDED FOR
  - -- EQUIPMENT CHECKOUT
  - -- BASELINE TESTING
  - -- FUNCTIONAL MONITORING
- EXPLICIT SATISFACTORY FUNCTIONAL PERFORMANCE CRITERIA ARE NEEDED, USUALLY IN TERMS OF TOLERANCES ON EQUIPMENT OUTPUT PARAMETERS (VOLTAGE, ETC.)

MOUNTING ON TEST TABLE

- IEEE-344 REQUIRES EQUIPMENT TO BE MOUNTED IN A MANNER WHICH SIMULATES INTENDED SERVICE MOUNTING

- BOLTS, BRACKETS, ETC., MUST BE THE SAME.

- THE EFFECT OF ELECTRICAL CONNECTIONS, CONDUIT, NOZZLE LOADS, ETC., SHOULD BE INCLUDED

- BECAUSE OF THE IMPORTANCE OF ANCHORAGE FAILURES OBSERVED DURING EARTHQUAKES, THE QUESTION OF MOUNTING DURING TESTING IS OF <u>CRUCIAL</u> CONCERN.

MONITORING OF TRS AND EQUIPMENT ACCELERATION

- IEEE-344 REQUIRES SUFFICIENT MONITORING EQUIPMENT TO EVALUATE THE TRS AND EQUIPMENT PERFORMANCE BEFORE, DURING AND AFTER THE TEST.

- IEEE-344 RECOMMENDS MONITORING ENOUGH POINTS ON THE EQUIPMENT TO EVALUATE THE METHOD CHOSEN FOR THE TEST.

- THE LOCATION OF ALL MONITORING SENSORS SHALL BE DOCUMENTED.

EXPLORATORY TESTS

- MAY BE PERFORMED TO

  -- AID IN DETERMINING THE APPROPRIATE TEST METHOD

  -- IDENTIFY EQUIPMENT RESONANCES (IF RIGID, PERHAPS ANALYSIS WILL DO)

  -- IDENTIFY CROSS-COUPLING OF RESPONSES (AND HENSE NEED FOR BI-OR TRI-AXIAL TESTS)

- USUALLY PERFORMED AT LOW LEVEL (SAY 0.2G) WITH SINE SWEEP TEST (2 OCTAVES PER MINUTE) OVER FREQUENCY RANGE OF INTEREST.

- NOTE: BECAUSE OF NON-LINEARITIES, RESONANCES MAY <u>NOT</u> BE EXCITED AT LOW TEST LEVELS - OR MAY SHIFT IN FREQUENCY AT HIGH TEST LEVELS.

TESTING SEQUENCE

- IEEE-344 REQUIRES AT LEAST ONE OBE TEST FOLLOWED BY SSE TEST.
- UNLESS OTHERWISE JUSTIFIED, TESTING WITH 5 OBE FOLLOWED BY SSE IS REQUIRED.

SINGLE VS. BIAXIAL VS. TRIAXIAL TESTS

- SEISMIC GROUND MOTION OCCURS SIMULTANEOUSLY IN ALL DIRECTIONS IN A RANDOM FASHION. SO IN PRINCIPLE, TEST INPUT MOTION SHOULD BE IN ALL PRINCIPAL AXES SIMULTANEOUSLY.

- HOWEVER, TWO AXIS TEST FACILITIES ARE LIMITED, AND THREE AXIS FACILITIES ALMOST NON-EXISTANT. SO SEVERAL ALTERNATIVES ARE ALLOWED.

- SINGLE AND BIAXIAL TESTS MUST BE APPLIED CONSERVATIVELY TO ACCOUNT FOR ABSENCE OF MOTION IN ORTHOGONAL DIRECTION.

- SINGLE AND BIAXIAL TESTS SHOULD BE APPLIED IN SEVERAL DIRECTIONS RELATIVE TO EQUIPMENT.

SINGLE AXIS TESTS

- IEEE ALLOWS THESE IF

  -- TESTS CONSERVATIVELY REFLECT SEISMIC EVENT AT EQUIPMENT MOUNTING LOCATION, OR

  -- THE EQUIPMENT CAN BE SHOWN TO RESPOND INDEPENDENTLY IN THREE ORTHOGONIAL DIRECTIONS.

  -- THE IN-SERVICE EQUIPMENT MOTION IS UNI-DIRECTION (E.G., A DEVICE MOUNTED IN A CABINET WHICH AMPLIFIES MOTION IN ONLY ONE DIRECTION.

- OTHERWISE, MULTIAXIAL TESTING IS REQUIRED.

BIAXIAL TESTS

- MINIMUM REQUIREMENT FOR MULTI-AXIAL TESTING IN IEEE-344 IS BIAXIAL WITH SIMULTANEOUS INPUTS IN PRINCIPAL HORIZONTAL AND VERTICAL AXES.

- IF INPUTS ARE INDEPENDENT AND RANDOM (COHERENCE LESS THAN 0.3) TEST MUST BE PERFORMED IN TWO STEPS, WITH EQUIPMENT ROTATED (HORIZONTAL PLANE) 90° BETWEEN TESTS. (PREFERRED)

- IF INDEPENDENT RANDOM INPUT NOT USED (E.G., SINGLE FREQUENCY TESTS) 4 TESTS ARE REQUIRED.

CHOICE OF WAVEFORM AND DURATION

- THE TEST TABLE MOTIONS (WAVEFORMS) SHOULD Shall

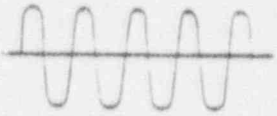
  - SIMULATE REAL EARTHQUAKE WITH RESPECT TO ENERGY AND DURATION
  - BE AS INCOHERENT AS POSSIBLE FOR MULTI-AXIS TESTS
  - ENVELOPE THE RRS
  - NOT INCLUDE FREQUENCIES ABOVE THE ZPA OF THE RRS
  - HAVE A DURATION AT LEAST EQUAL TO STRONG MOTION PORTION OF TIME HISTORY USED TO GET THE RRS FOR THE SSE. — 15 sec long

- COMMON INPUT WAVEFORMS ARE

  - SINGLE FREQUENCY
  - MULTIPLE FREQUENCY

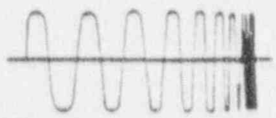
SINGLE FREQUENCY WAVEFORMS

- CONTINUOUS SINE



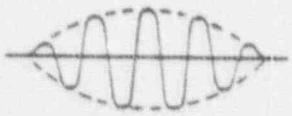
  - -- CONCENTRATES ENERGY AT ONE FREQUENCY
  - -- MINIMUM TEST EQUIPMENT
  - -- DOES NOT EXCITE MULTIPLE MODES
  - -- MORE AMPLIFICATION THAN SEISMIC EVENT

- SINE SWEEP



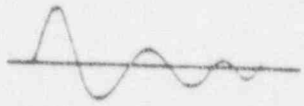
  - -- SAME AS ABOVE
  - -- PRODUCES A THOROUGH SEARCH FOR NATURAL FREQUENCIES

- SINE BEAT



  - -- CONCENTRATES ENERGY AT ONE FREQUENCY
  - -- MORE TYPICAL OF A SEISMIC EVENT
  - -- USED TO MODEL LOW CYCLE FATIGUE EFFECTS

- DECAYING SINE



  - -- SIMILAR TO SINE BEAT

MULTI-FREQUENCY WAVEFORMS

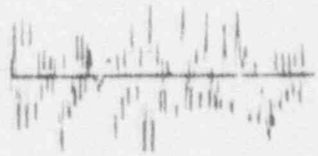
- REAL TIME HISTORY

  -- EXCITES MULTIPLE MODES

  -- USUALLY TOO SPECIFIC

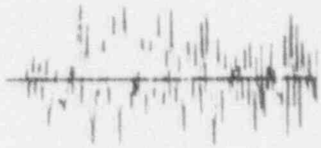
  -- NOT GENERALLY USED

- SYNTHESIZED TIME HISTORY



  -- SAME AS ABOVE

- RANDOM



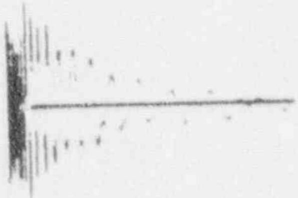
  -- EASY TO GENERATE

  -- CLOSELY MATCHES SEISMIC GROUND MOTION

  -- EXCITES MULTIPLE MODES

  -- MINIMUM DURATION 15 SECONDS

- COMPLEX [SUMMATION OF DECAYING SINES]



  -- COMPLEX CAN BE MADE TO FIT ODD-SHAPED RESPONSE SPECTRUMS, BUT DURATION IS NOT REALISTIC.

SOME IMPORTANT QUESTIONS FOR A SEISMIC TEST

---

1. IS THE RRS REASONABLE FOR THE INTERNAL EQUIPMENT LOCATIONS? IF NARROW BAND, IS THERE A JUSTIFICATION? IS DAMPING LEVEL APPROPRIATE FOR EQUIPMENT BEING TESTED?

2. IS ITEM TO BE TESTED COMPLETE? ARE APPENDAGES OR INTERFACE CONNECTIONS MISSING?

3. ARE FUNCTIONAL PARAMETERS AND PERFORMANCE PROPERLY DEFINED?

4. ARE NORMAL LOADINGS AND ENVIRONMENT BEING PROPERLY INCLUDED? ANY MISSING?

5. IS MOUNTING THE SAME AS FOR SERVICE?

6. IN SEARCHING FOR EQUIPMENT ~~RESOURCES~~ resonances, HAS SINE OR SINE SWEEP TEST BEEN USED? OTHER WAVE FORMS MAY NOT BE APPROPRIATE.

7. ARE OBE TESTS BEING PERFORMED BEFORE SSE TEST?

8. HAS CONSERVATISM BEEN USED IN DEFINING SINGLE AXIS AND BIAXIAL TESTS?

— Damping for Electrical Eq. is normally 3-5%

—

CONTINUED

9. IF A SINGLE AXIS TEST, HAS CROSS-AXIS COUPLING BEEN RULED OUT?

10 IF BIAXIAL TEST WITH INDEPENDENT INPUT, HAS COHERENCE BETWEEN INPUTS BEEN CHECKED. HAVE MULTIPLE TESTS WITH EQUIPMENT ROTATIONS HAVE BEEN PERFORMED.

11. DOES TRS ENVELOP THE RRS? ARE DAMPING FOR RRS AND TRS THE SAME? IS ITS DURATION APPROPRIATE?

required response Spectra

HYDROGEN BURN CONSIDERATIONS

After the accident at Three Mile Island - Unit 2, the issue of hydrogen produced by chemical reaction between steam and fuel cladding material received much attention. The original concern was that a hydrogen deflagration or detonation would produce pressure spikes that would rupture the containment. For some reactor designs, it was shown that hydrogen burns would not be a serious threat. For other reactor designs, including Mark III BWR's and ice condenser PWR's, hydrogen was shown to be a problem, and the commission proposed a rule to address the concern. The purpose of this section is to present an overview of some of the aspects of qualifying equipment for hydrogen burn environments.

Hydrogen Control Rule

The hydrogen control rule was tentatively approved on December 10, 1984, and is an amendment to 10 CFR 50. It applies to Mark III BWRs and ice condenser PWRs. (A rule concerning hydrogen control in large dry PWR containments is still pending.) The rule requires Mark III BWR and ice condenser PWR facilities to*

1. provide hydrogen control systems that can handle large amounts of hydrogen (One solution is to ignite the hydrogen before it reaches concentration levels at which burning or detonation would threaten containment integrity.)

2. demonstrate the survivability/qualification of containment and safety systems during and following a hydrogen burn

3. perform and submit analyses concerning hydrogen control and survivability/qualification of containment and safety systems.

The rule has many implications; the one of interest here is that some Class 1E equipment may have to be qualified for various hydrogen burn environments.

Hydrogen Burn Environment

The hydrogen burn environment is different from a typical IEEE 323 test profile in that the transient effects of the environment are more important, and the equipment is exposed to higher temperatures for a shorter time. The typical LOCA environmental test profile has a 10 second ramp to 340 F which is maintained for several hours. A hydrogen burn environment is likely to see temperature increases on the order of 1000 F with a ramp time of roughly 30 seconds, but the temperature is not maintained and drops off relatively rapidly (depending on many factors).

The hydrogen burn environment is very dependant on the specific reactor. Containment size and geometry as well as how much hydrogen is generated are very important. Another aspect is how the hydrogen is burned - all in one relatively high concentration burn or in multiple burns with lower hydrogen concentrations.

* This information was taken from The NRC Calendar, Volume III, Number 49.

Because hydrogen burns are transient phenomena, heat flux is the important paramenter instead of temperature. The heat flux results from the "cloud" of hot gases remaining after a burn, not from the burn itself. The gas then dumps its energy to walls, equipment, and other structures, producing temperature rises and thermal stresses. Thermal damage is the main concern from an equipment survival standpoint, although pressure may serve to drive in moisture after seals, etc. are damaged. Note that the equipment itself is not likely to experience as high temperatures as the gas because there is not enough time for thermal equilibrium to occur. (In LOCA simulations there is enough time for the equipment temperature to equilibrate with the environment temperature.)

Local variations in the hydrogen burn environment are very important. Shielding plays a major role, and the survivability of equipment is very dependant on its specific loaction within the containment. Concrete and steel are good heat sinks; equipment located near the containment walls or other massive structures will be somewhat protected. Equipment located in large open volumes will be exposed to more severe conditions and will receive higher heat fluxes from the hot gas environment.

Simulating the hydrogen burn environment is very difficult because the thermodynamics do not scale. Hydrogen burns in containment-size volumes do not behave at all like hydrogen burns in test volumes. In addition to the surface-area-to-volume ratios being orders of magnitude different, the dominant heat transfer mechanisms (i.e. convection and thermal radiation) depend on geometrical factors such as path length and vertical dimension. In a test, the hydrogen burn environments must be simulated by means other than actually burning hydrogen in a test volume. At Sandia this is done using the Solar Power Tower to provide transient heat fluxes to simulate the thermal environment of a hydrogen burn. It has not yet been specified exactly how to qualify equipment for hydrogen burn environments; research will likely continue in this area. Thus, the material presented in this section is intended only to give an overview of how the hydrogen burn environment is different from the standard LOCA environment and what considerations are important regarding equipment survival in hydrogen burns.

Effects on Equipment

As stated before, from an equipment survival standpoint, heat flux is the parameter of interest in a hydrogen burn environment. Each piece of equipment will respond differently to hydrogen burns because of differences in thermal mass, geometry, and location of the equipment; shielding effects; and the hydrogen burn itself. For a given heat flux environment, a more massive device, such as a pressure transmitter, will have a smaller temperature rise than a thin-walled piece of equipment like a junction box. Equipment located in the middle of a large open volume will receive much larger heat fluxes than identical equipment located near a concrete wall or other thermally massive structure. Cable installed in conduit will experience significantly smaller temperature rises than exposed cable. Components exposed to multiple burns may see a ratchet effect in their temperature response; that is, there may be insufficient time between burns for the component to return to its original temperature.

In additon, the temperatures rises are not likely to be uniform throughout a piece of equipment; this complicates the survivability analysis. For example, orientation of a particular piece of equipment may play an important role if sub-components are vulnerable to temperature. Mounting the equipment such that the vulnerable portion is near a wall or other protective structure may be enough to assure survival.

Ultimate failure of equipment exposed to hydrogen burns is usually due to moisture. The thermal environment weakens or damages seals and insulation, leaving a path for water to create shorts or grounds.

Predicting equipment failure is difficult. In the first place, it is nearly impossible to accurately define a hydrogen burn environment. Once the environmental parameters (such as heat flux) are chosen and the local surroundings (shielding, heat sinks) are defined, established heat transfer computer codes can be used to predict temperature responses of equipment, but reliable computer models of the equipment must be available. And finally, the heat transfer codes will merely calculate the thermal response of the equipment, not whether it fails or survives.

One approach to equipment qualification for hydrogen burns would be to use the above techniques as well as possible, including sufficient margin to account for uncertanties. Then, if equipment temperatures are shown to be less than the LOCA qualification temperatures to which the equipment has already been qualified, the equipment could perhaps be considered qualified for that particular hydrogen burn environment.

Hydrogen Burn Considerations

The hydrogen control rule requires Mark III BWR and ice condenser PWR facilities to

1. provide hydrogen control systems that can handle large amounts of hydrogen

2. demonstrate the survivability / qualification of containment and safety systems during and following a hydrogen burn

3. perform and submit analyses concerning hydrogen control and survivability / qualification of containment and safety systems.

Recent Studies Indicate High Temperatures in TMI–2 Hydrogen Burn

Paper – 450F

Polymers – 480F

"Other objects" – 165 – 500F

Ref. – "Estimated Temperatures of Organic Materials in the TMI–2 Reactor Building during Hydrogen Burn," Schutz and Nagata, GEND–INF–023.

Sandia National Laboratories

— Heat Flux (important parameter)

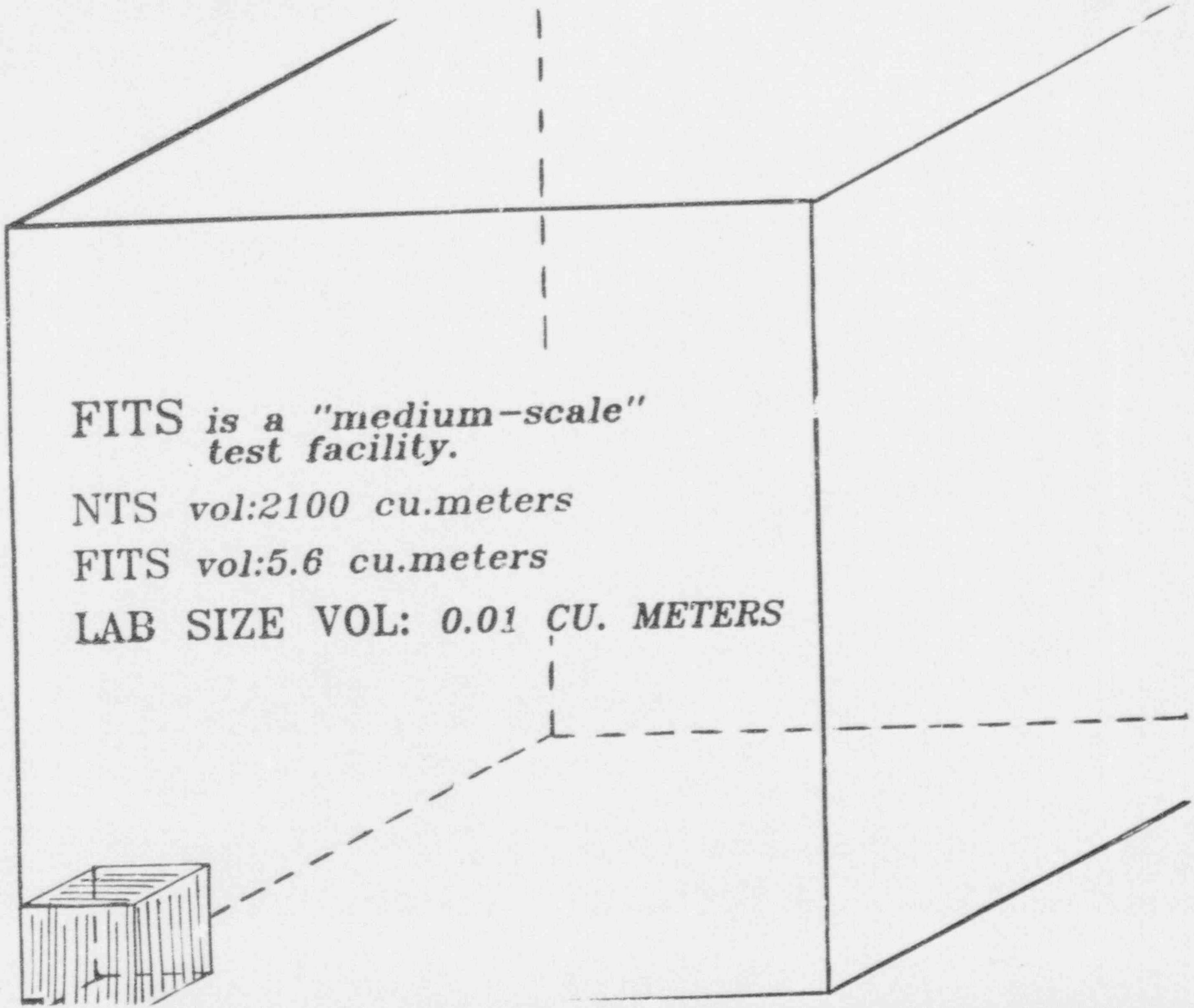
Hydrogen Burns are Transient Phenomena.

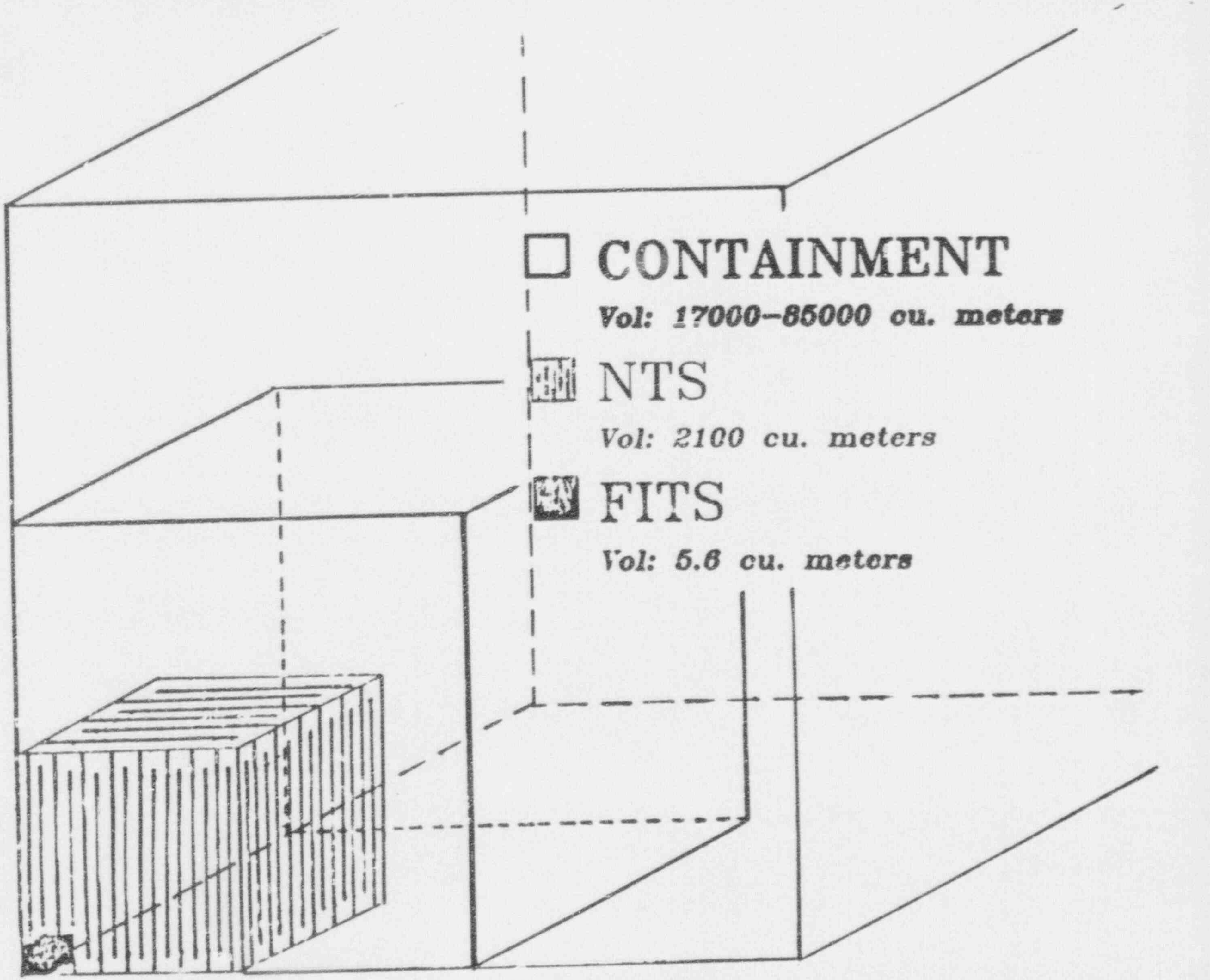
1. 1000-2000 °F temperature rises in less than 1 min.
2. immediate decay
3. equipment response lago

Heat flux (not temperature) is the important parameter.

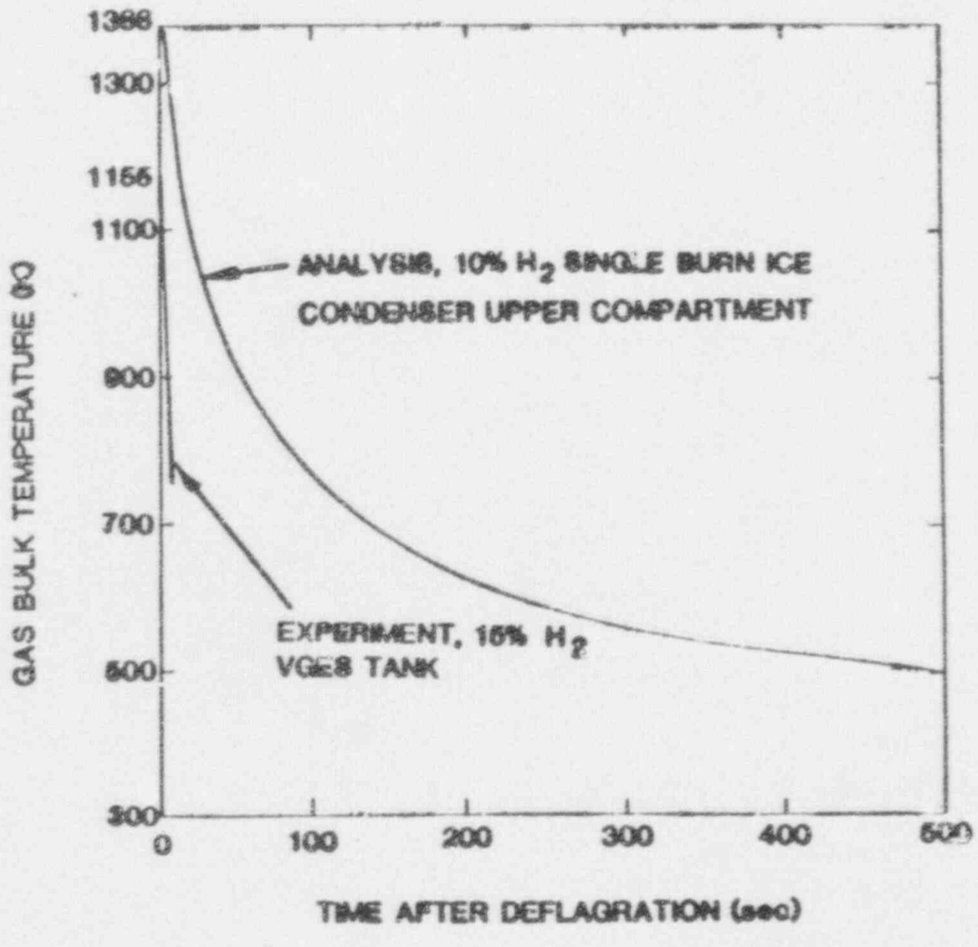
1. heat flux comes from 'cloud' of hot gases, not hydrogen flame [Radiation Convection]

2. environment can't be simulated with an oven


FITS is a "medium-scale" test facility.
NTS vol:2100 cu.meters
FITS vol:5.6 cu.meters
LAB SIZE VOL: 0.01 CU. METERS


CONTAINMENT
Vol: 17000–85000 cu. meters
NTS
Vol: 2100 cu. meters
FITS
Vol: 5.6 cu. meters

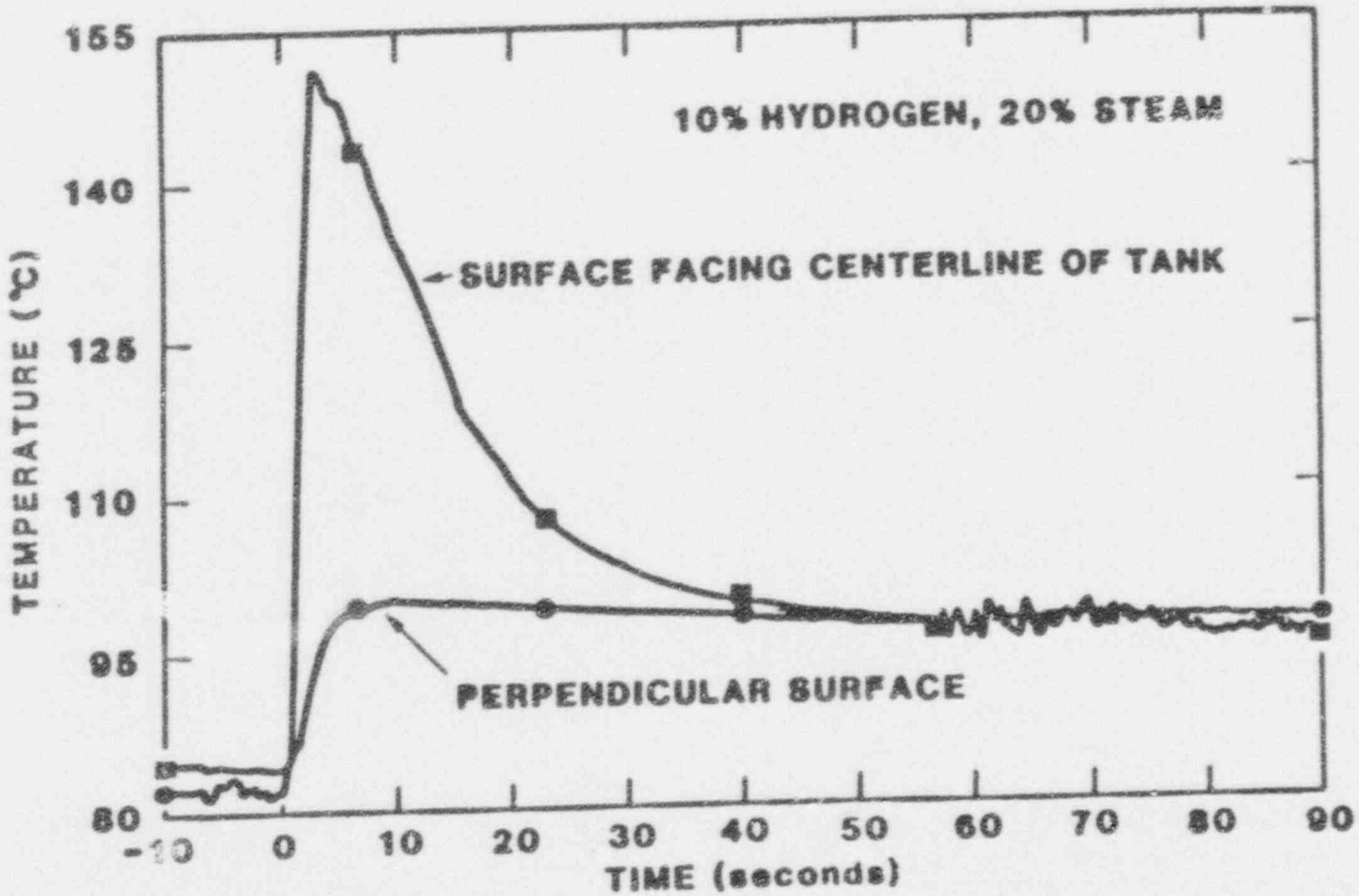
VOLUME INFLUENCES PULSE DURATION



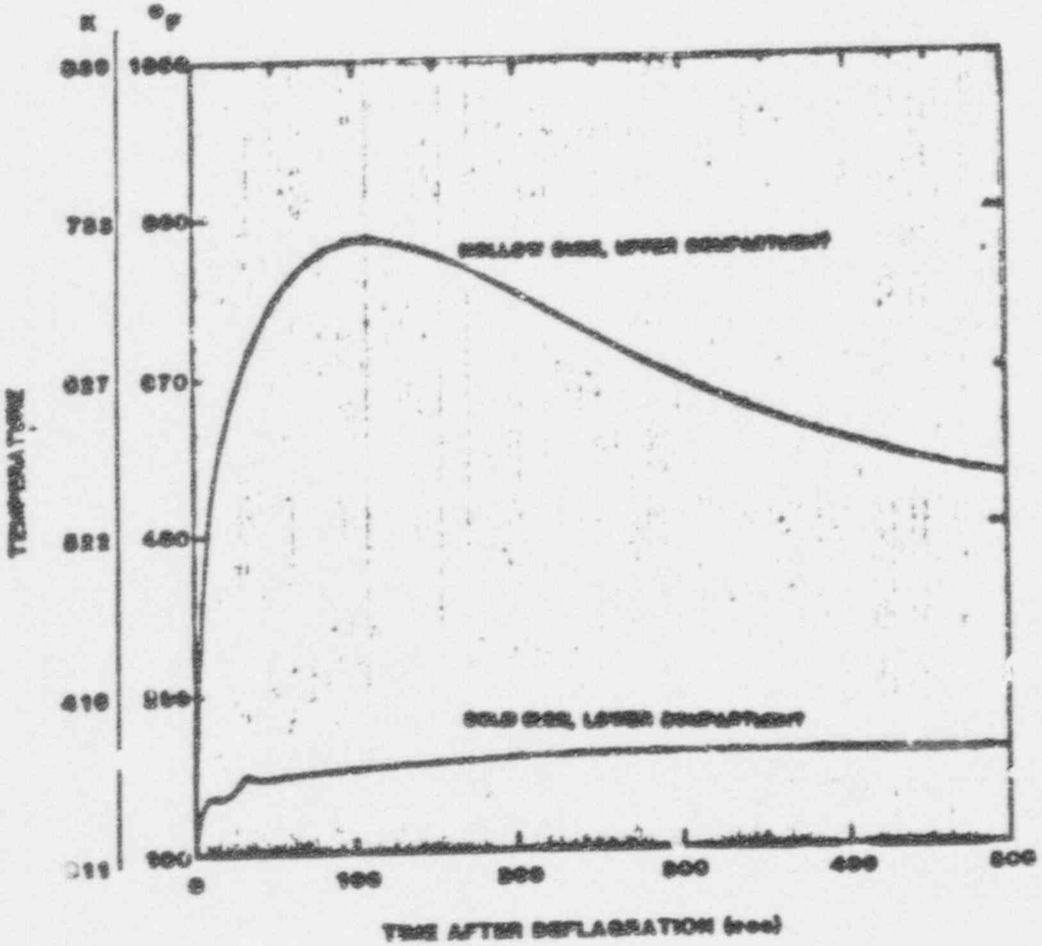
Local variations in the hydrogen burn environment are very important.

1. Shielding
2. Heat Sinks
3. Volume of Compartment
4. Orientation of Equipment
5 Thermal mass of Equipment

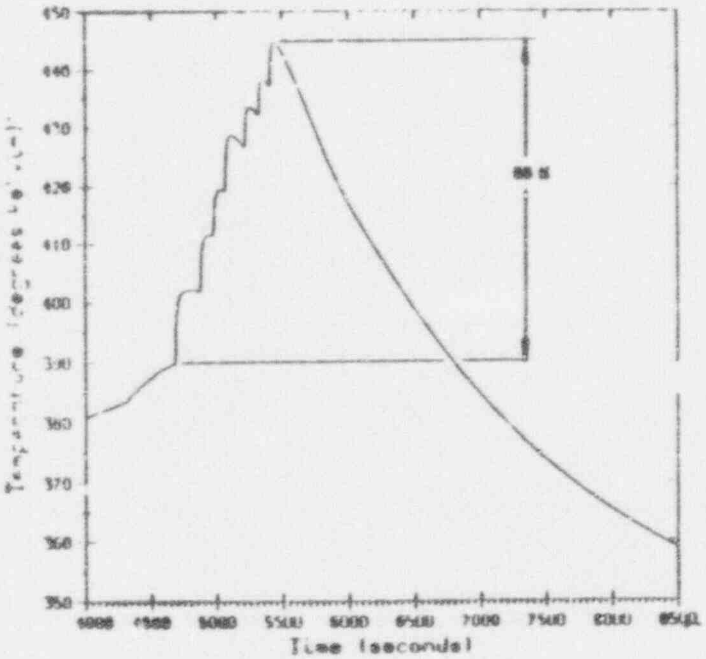
Local temperature response of component depends on component orientation.



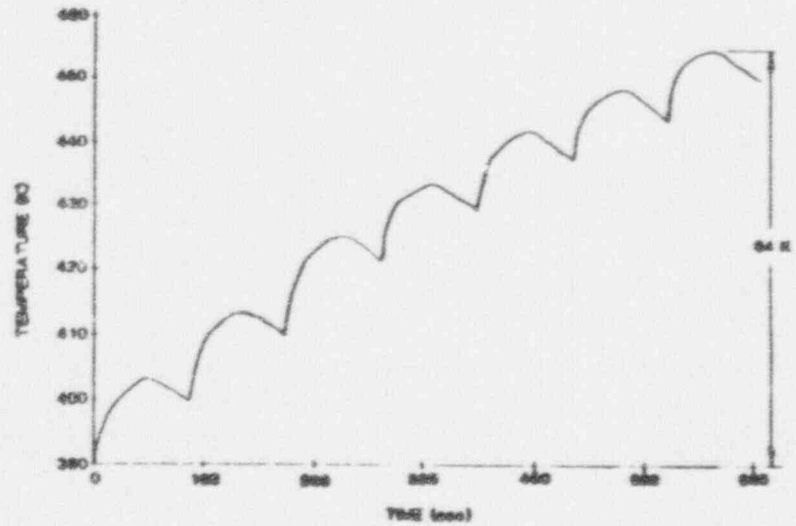
Analyses of Single, Global Burns used to Estimate Bounds of HBS Problem.



MULTIPLE BURN SIMULATIONS HAVE SHOWN TEMPERATURE RATCHETING



ECTR



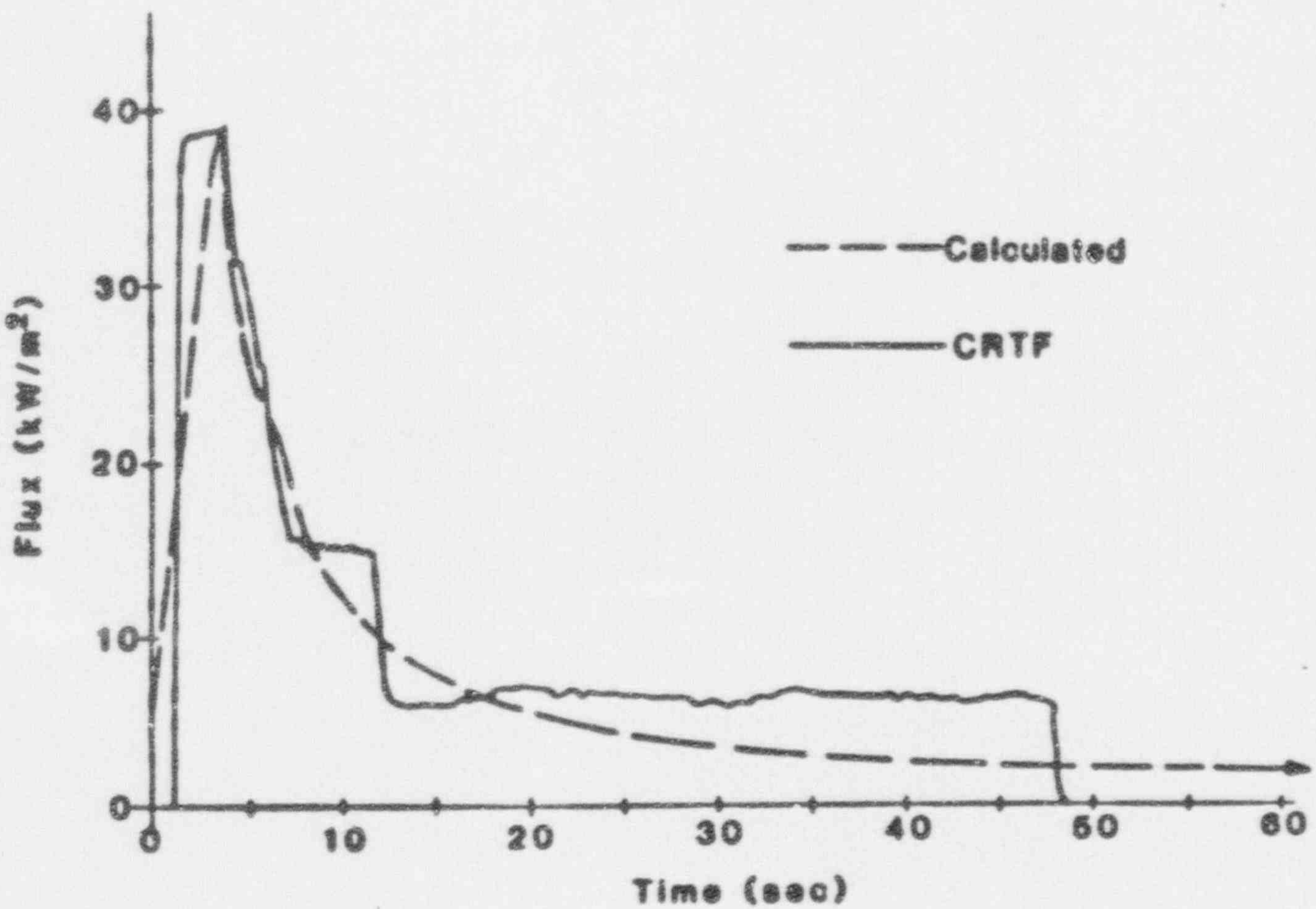
CRTF

Simulating the hydrogen burn environment is very difficult.

1. thermodynamics do not scale
   a) volume effects
   b) heat transfer mechanisms

2. must use method other than burning hydrogen in a test volume

CRTF PULSE SIMULATION



Equipment failures from hydrogen burns are most likely due to moisture intrusion after seals, insulation, etc., are thermally damaged.

Predicting equipment failure is difficult.

1. hard to define environment

2. dependant on local surroundings

3. thermal response can be calculated, but does not indicate failure/survival

4. compare to LOCA qualification

   equipment temperature < LOCA → qualified

   equipment temperature > LOCA → ?

Technical Report TS1982-YJK-2

ANALYSIS

OF

β-RADIATION EFFECT

R. J. Gehm
J. R. Marth
F. R. Postma
E. S. Reed

Y. J. Kim yjk
May, 1982

CONTENTS

Key Words: β-radiation, penetration, cumulative dose.

INTRODUCTION

Recently some customers have raised the question of β-radiation effects. Since β-radiation is essentially a bombardment with electrons, it can be handled similarly to our electron beam processing. Since β-radiation has orders of magnitude lower penetration capability in comparison with γ-radiation, most of the electrons do not penetrate much beyond the jacket thickness, which is usually 45 mils. In other words, the insulation material is affected little under most situations.

To analyze the situation more quantitatively, the β-radiation data supplied by Bechtel (Appendix I) are taken and classified into two groups. With the first group, it is demonstrated that β-radiation below 0.5 MeV does not penetrate beyond the jacket thickness in our usual cable construction. With the second group, it is demonstrated that the total cumulative β-radiation dosage is too low to be a major concern even if the β-ray penetrates into the insulation above 0.5 MeV.

CONCLUSION

β-radiation will not cause an electrical breakdown during the 720 hour period after LOCA.

III. ANALYSIS

A. Effect of β-Radiation Below 0.5 MeV

Effective penetration depth of high energy electron beam is well established as shown in Figs. 1 and 2. The figures are taken from chapter 3 of the reference book shown in Chapter IV. The figures indicate that electrons have relatively low penetrating capability and the maximum ionization occurs at much shallower depth than the maximum penetration. Since the ionization is what causes chemical reaction, effect of the electron beam diminishes quickly near the end of its maximum penetration depth.

Similarly to the figures shown, Charlesby gives Equation (1) on page 34 of the reference book for β-radiation:

$$d = 0.35\ E \rho^{-1}\ \text{cm} \qquad (1)$$

III. ANALYSIS

A. Effect of β-Radiation Below 0.5 MeV (Continued)

Here d denotes the maximum penetration depth in cm, E energy level in MeV, and ρ density of the material in g/cc. From Eq. (1) the depth of the cable jacket material, which will be penetrated by 0.5 MeV β-radiation, can be calculated as follows:

$$\begin{aligned} d &= (0.35)\,(0.5)/(1.50) \\ &= 0.117 \text{ cm} \\ &= 0.0459 \text{ mils.} \end{aligned} \qquad (2)$$

Here the density of the jacket material is taken as 1.5 g/cc. This calculation demonstrates that essentially all the effect due to β-energy spectra between zero and 0.500 MeV is stopped by the jacket, which is usually 45 mils in thickness. Hence, we need not be concerned about the effect of β-radiation within the spectral range, i.e., from zero to 0.5 MeV.

B. Effect of β-Radiation at the Energy Level Above 0.50 MeV

Total energy received from the β-radiation spectra between 0.50 and 3.0 MeV may be calculated by integrating the energy over the time and the energy spectra. Hence, the total cumulative energy received is calculated by integrating the radiation intensity over the 720 hour period at each spectral interval, and then, sum the values over the whole spectra as shown in Table I. Since

$$1 \text{ eV} = 1.602 \times 10^{-12} \text{ ergs} \qquad (3)$$

and

$$1 \text{ rad} = 100 \text{ ergs/g.} \qquad (4)$$

III. ANALYSIS

B. Effect of β-Radiation at the Energy Level Above 0.50 MeV (Continued)

we can calculate the total radiation dose received as follows:

From Table I, the total energy received is:

$$E_T = 5.18882 \times 10^{12} \text{ MeV/cc}$$

$$= 5.18882 \times 10^{12} \times 10^{6} \text{ eV/cc}$$

$$= 5.18882 \times 10^{12} \times 10^{6} \text{ (eV/cc)}$$

$$\times 1.602 \times 10^{-12} \text{ (ergs/eV)}$$

$$= 8.31249 \times 10^{6} \text{ (ergs/cc)} \qquad (5)$$

For the material of density 1.5 (g/cc)

$$E_T = 8.31249 \times 10^{6} \text{ (ergs/cc)}/1.5 \text{ (g/cc)}$$

$$= 5.5417 \times 10^{6} \text{ (ergs/g)} \qquad (6)$$

With Eq (4) we have:

$$E_T = \frac{5.5417 \times 10^{6} \text{ (ergs/g)}}{100 \text{ (ergs/g)}}$$

$$= 5.5417 \times 10^{4} \text{ (rads)}$$

$$= 0.055417 \text{ (Mrads)}$$

Hence, the maximum irradiation dose received by any part of the insulation due to β-radiation is only 0.0554 Mrads. Effect of this dosage level is insignificant in polyolefin based insulation material.

IV. REFERENCE

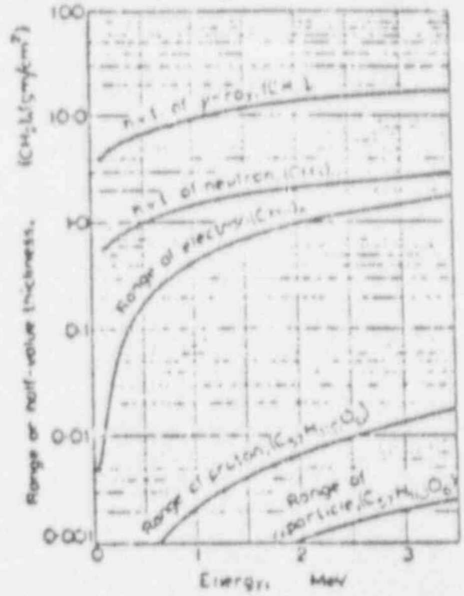
A. Charlesby, "Atomic Radiation and Polymers", Pergamon Press, 1960.

TABLE I

β-Radiation Dose Received Above 0.5 MeV

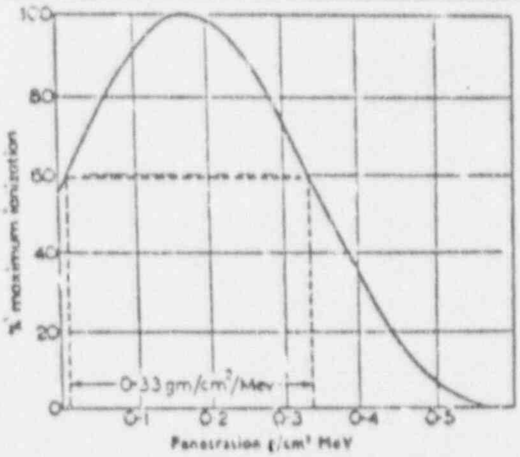
Range of Radiation Potential (MeV)	Median Potential (MeV)	Total Energy * Received During 720 Hour Period (MeV/cc)
0.60 - 0.80	0.700	1.21822×10^{12}
0.80 - 1.00	0.900	2.34158×10^{10}
1.00 - 1.25	1.125	4.96981×10^{11}
1.25 - 1.50	1.375	3.08394×10^{12}
1.50 - 2.00	1.750	3.66263×10^{11}
	Total	5.18882×10^{12}

* The cumulative energy received over 720 hour period shown here is based on the information supplied by Bechtel which is attached as Appendix I.



The range or half-value thickness of various forms of high energy radiation in materials similar to polyethylene.

Figure 1.



Ionization density vs. penetration for single irradiation from one side.

Figure 2.

REQUEST FOR TELECOPY by PDCC

LIMERICK GENERATING STATION

UNITS 1 & 2, Job No. 8031

TO: JIM MARTH / JOHN KIM (Name)

ROCKBESTOS COMPANY (Company)

NEW HAVEN, CONNECTICUT 06504 (City & State)

VIA 203-773-0436 (Receiving Facsimile Phone Number)

FROM: W. McDANIEL

LIMERICK PROJECT - JOB 8031

BECHTEL POWER CORP. S. F., CA

FACSIMILE PHONE NO. - 415-768-5082 (Xerox 200)

INFORMATION PHONE NO. - 415-768-8804

Number of pages telecopied (including this page) 12

Date 4-26-82

APPROVED FOR TELECOPIER TRANSMISSION

Remember--Xeroxes only accepted for transmission
Red ink does not telecopy
Margins of 1/2-inch must be on all sides

DEAR MR. MARTH

ENCLOSED YOU WILL FIND THE BETA ENERGY INFORMATION REQUESTED DURING THE TELECON BETWEEN MR. JOHN KIM OF ROCKBESTOS AND ATIF AMMAR OF BECHTEL ON 4-26-82.

BETA DOSE CALCULATION
TIME AFTER LOCA= .00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.0110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.0500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.46606+07
0.15 - 0.20	1.27764+07
0.20 - 0.30	2.98439+07
0.30 - 0.40	3.64860+08
0.40 - 0.50	1.16582+08
0.50 - 0.60	.00000
0.60 - 0.80	4.91409+08
0.80 - 1.00	2.59677+07
1.00 - 1.25	5.50603+08
1.25 - 1.50	1.14228+09
1.50 - 2.00	1.35653+08
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	2.93464+09

BETA DOSE CALCULATION
TIME AFTER LOCA= .50 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.3110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.44662+07
0.15 - 0.20	1.27530+07
0.20 - 0.30	2.76678+07
0.30 - 0.40	3.40466+06
0.40 - 0.50	1.08227+08
0.50 - 0.60	.00000
0.60 - 0.80	1.91539+08
0.80 - 1.00	2.48910+04
1.00 - 1.25	7.87206+05
1.25 - 1.50	2.61447+08
1.50 - 2.00	3.94727+01
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	1.00738+09

BETA DOSE CALCULATION
TIME AFTER LOCA= 1.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.0110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	UNDETERMINED
KR-83M	.0000	NOBLE GAS
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	UNDETERMINED
XE133M	.0000	NOBLE GAS
XE-133	1.0030-01	UNDETERMINED
XE135M	.0000	NOBLE GAS
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.43041+07
0.15 - 0.20	1.27295+07
0.20 - 0.30	2.56552+07
0.30 - 0.40	3.18240+08
0.40 - 0.50	1.00905+08
0.50 - 0.60	.00000
0.60 - 0.80	8.64727+07
0.80 - 1.00	2.38573+01
1.00 - 1.25	1.12567+03
1.25 - 1.50	1.92496+08
1.50 - 2.00	1.14819-65
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	8.00804+08

BETA DOSE CALCULATION
TIME AFTER LOCA= 2.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0000-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.8110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.39476+07
0.15 - 0.20	1.26825+07
0.20 - 0.30	2.20742+07
0.30 - 0.40	2.79184+08
0.40 - 0.50	8.88385+07
0.50 - 0.60	.00000
0.60 - 0.80	2.64234+07
0.80 - 1.00	2.19192-05
1.00 - 1.25	2.3022[illegible]-03
1.25 - 1.50	1.09040+08
1.50 - 2.00	9.72040-19
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	6.[illegible]

BETA DOSE CALCULATION
TIME AFTER LOCA= 4.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.0110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--8[illegible]	1.2560+00	HALOGEN
BR--8[illegible]	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.505[illegible]-01	NOBLE GAS
KR--87	1.2230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3[illegible]0+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.32021+07
0.15 - 0.20	1.25827+07
0.20 - 0.30	1.64057+07
0.30 - 0.40	2.18380+08
0.40 - 0.50	7.21869+07
0.50 - 0.60	.00000
0.60 - 0.80	4.71112+06
0.80 - 1.00	1.85034-17
1.00 - 1.25	9.62452-15
1.25 - 1.50	3.59697+07
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	4.27439+08

BETA DOSE CALCULATION
TIME AFTER LOCA= 8.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.9170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.8110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	UNDETERMINED
KR-83M	.0000	NOBLE GAS
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	UNDETERMINED
XE133M	.0000	NOBLE GAS
XE-133	1.0030-01	UNDETERMINED
XE135M	.0000	NOBLE GAS
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

TOTAL

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	6.17760+07
0.15 - 0.20	1.23948+07
0.20 - 0.30	9.25014+06
0.30 - 0.40	1.41137+08
0.40 - 0.50	5.43146+07
0.50 - 0.60	.00000
0.60 - 0.80	1.90714+05
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	4.01434+06
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	2.83078+08

BETA DOSE CALCULATION
TIME AFTER LOCA= 16.00 HOURS
CONTROL VOLUME= 7.14500000+06 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.6600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.8110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	5.90535+07
0.15 - 0.20	1.20249+07
0.20 - 0.30	3.39076+06
0.30 - 0.40	6.71602+07
0.40 - 0.50	3.83411+07
0.50 - 0.60	.00000
0.60 - 0.80	3.16374+02
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	5.04046+04
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	1.80021+08

BETA DOSE CALCULATION
TIME AFTER LOCA= 24.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	CURIES	BETA COMPONENT
I--131	1.8170-01	1.9660+07	HALOGEN
I--132	4.8600-01	2.0330+04	HALOGEN
I--133	4.0600-01	2.1990+07	HALOGEN
I--134	6.1000-01	2.6620-01	HALOGEN
I--135	3.6900-01	3.7410+06	HALOGEN
I--136	1.8110+00	.0000	HALOGEN
BR--83	3.1000-01	3.7790+03	HALOGEN
BR--84	1.2500+00	1.5180-07	HALOGEN
BR--85	8.3300-01	.0000	HALOGEN
KR-83M	.0000	2.0040+03	UNDETERMINED
KR-85M	2.9020-01	8.9370+05	NOBLE GAS
KR--85	2.5050-01	1.3140+06	NOBLE GAS
KR--87	1.3230+00	1.4800+02	NOBLE GAS
KR--88	3.6500-01	2.7590+05	NOBLE GAS
KR--89	1.2410+00	.0000	NOBLE GAS
XE133M	.0000	3.7210+06	UNDETERMINED
XE-133	1.0930-01	1.7410+06	NOBLE GAS
XE135M	.0000	7.9310-21	UNDETERMINED
XE-135	3.0200-01	3.0400+07	NOBLE GAS
XE-137	1.3700+00	.0000	NOBLE GAS
XE-138	6.6000-01	2.7390-17	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC-SEC
0.00 - 0.10	.00000
0.10 - 0.15	5.64282+07
0.15 - 0.20	1.16609+07
0.20 - 0.30	1.72490+06
0.30 - 0.40	3.44572+07
0.40 - 0.50	2.88820+07
0.50 - 0.60	.00000
0.60 - 0.80	5.24728-01
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	6.32729+02
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	1.33154+08

BETA DOSE CALCULATION
TIME AFTER LOCA= 96.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	CURIES	BETA COMPONENT
I--131	1.8170-01	1.5110+07	HALOGEN
I--132	4.8600-01	5.0360-06	HALOGEN
I--133	4.0600-01	1.8600+06	HALOGEN
I--134	6.1000-01	2.5310-26	HALOGEN
I--135	3.6900-01	2.0630+03	HALOGEN
I--136	1.8110+00	.0000	HALOGEN
BR--83	3.1000-01	3.6750-06	HALOGEN
BR--84	1.2560+00	.0000	HALOGEN
BR--85	8.3300-01	.0000	HALOGEN
KR-83M	.0000	4.2850-09	UNDETERMINED
KR-85M	2.9020-01	1.0850+01	NOBLE GAS
KR--85	2.5050-01	1.2940+06	NOBLE GAS
KR--87	1.3230+00	1.1470-15	NOBLE GAS
KR--88	3.6500-01	5.1370-03	NOBLE GAS
KR--89	1.2410+00	.0000	NOBLE GAS
XE133M	.0000	1.4590+06	UNDETERMINED
XE-133	1.0030-01	1.1560+06	NOBLE GAS
XE135M	.0000	.0000	UNDETERMINED
XE-135	3.0200-01	1.2770+05	NOBLE GAS
XE-137	1.3700+00	.0000	NOBLE GAS
XE-138	6.6000-01	.0000	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	3.74675+07
0.15 - 0.20	8.87188+06
0.20 - 0.30	1.04747+06
0.30 - 0.40	1.27082+05
0.40 - 0.50	2.44025+06
0.50 - 0.60	.00000
0.60 - 0.80	4.98905-26
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	4.90365-15
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	4.99542+07

BETA DOSE CALCULATION
TIME AFTER LOCA= 240.00 HOURS
CONTROL VOLUME= 1.14500000+16 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-SUB(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.8110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

BETA ENERGY SPECTRA

ENERGY (MEV)	MEV/CC*SEC
0.00 - 0.10	.00000
0.10 - 0.15	1.65103+07
0.15 - 0.20	5.13465+06
0.20 - 0.30	1.01508+06
0.30 - 0.40	2.19944+00
0.40 - 0.50	1.74491+04
0.50 - 0.60	.00000
0.60 - 0.80	.00000
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	.00000
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	2.26775+07

BETA DOSE CALCULATION
TIME AFTER LOCA= 720.00 HOURS
CONTROL VOLUME= 1.14500000+10 CC
VOLUME DENSITY = 1.2930000-03 G/CC
THERE ARE 21 ISOTOPES

ISOTOPE	E-AVG(MEV)	BETA COMPONENT
I--131	1.8170-01	HALOGEN
I--132	4.8600-01	HALOGEN
I--133	4.0600-01	HALOGEN
I--134	6.1000-01	HALOGEN
I--135	3.6900-01	HALOGEN
I--136	1.8110+00	HALOGEN
BR--83	3.1000-01	HALOGEN
BR--84	1.2560+00	HALOGEN
BR--85	8.3300-01	HALOGEN
KR-83M	.0000	UNDETERMINED
KR-85M	2.9020-01	NOBLE GAS
KR--85	2.5050-01	NOBLE GAS
KR--87	1.3230+00	NOBLE GAS
KR--88	3.6500-01	NOBLE GAS
KR--89	1.2410+00	NOBLE GAS
XE133M	.0000	UNDETERMINED
XE-133	1.0030-01	NOBLE GAS
XE135M	.0000	UNDETERMINED
XE-135	3.0200-01	NOBLE GAS
XE-137	1.3700+00	NOBLE GAS
XE-138	6.6000-01	NOBLE GAS

TOTAL

BETA ENERGY SPECTRA

ENERGY (MEV)	(MEV/CC/SEC
0.00 - 0.10	.00000
0.10 - 0.15	1.07638+06
0.15 - 0.20	8.29060+05
0.20 - 0.30	9.15517+05
0.30 - 0.40	3.14336-16
0.40 - 0.50	1.22984-03
0.50 - 0.60	.00000
0.60 - 0.80	.00000
0.80 - 1.00	.00000
1.00 - 1.25	.00000
1.25 - 1.50	.00000
1.50 - 2.00	.00000
2.00 - 3.00	.00000
3.00 - 10.0	.00000
TOTAL	2.82096+06

QUALITY ASSURANCE AND THE MECHANICS OF QUALIFICATION

Introduction:

So far in this course we have discussed several important technical issues. These included:

1. Were functional performance requirements adequately specified and demonstrated during the qualification effort?

2. Were the environmental conditions appropriately specified and enveloped during the qualification effort?

3. Were the equipment interfaces and installation practices properly tested?

4. What are technical issues associated with hydrogen burn and seismic qualification?

Regulatory requirements and guidance associated with these technical issues are defined in 10 CFR 50.49, Reg Guide 1.89, IEEE Std. 323-1974 and related documents.

We now wish to discuss the question: Was the qualification program performed in a quality manner? The regulatory requirements and guidance concerning "quality" are contained in 10 CFR 50. App B, Reg Guide 1.89, and IEEE Std 323-1974. Our discussion of "quality" includes several major aspects:

1. First, we will discuss the regulatory qualification perspective and compare it to a different industry perspective. This will aid your understanding of inspection experiences.

2. Second, we will discuss different types of inspections. In a broad way we will consider relevant issues for an inspection of a utility or A/E, for a test laboratory, and for a manufacturer.

3. Third, we will discuss qualification documentation and practices requirements, including:

   a. The purchase specification
   b. Test plan requirements
   c. Test procedure requirements
   d. Test documentation requirements
   e. The review process
   . The certification question

Fifth, NRC requirements assume plant-specific monitoring of qualification activities. In contrast, until recently, parts of industry have only performed onsite monitoring of production activites. This occurs because generic qualification activites were performed prior to initiation of the purchase order.

Types of Inspections:

There are several types of facilities that one may inspect. We can divide the facilities into several major categories, namely:

1. Facilities that generate qualification requirements and review qualification submittals to assure that qualification requirements have been satisfied. This includes utilities, A/E's, NSSS vendors, and consultants.

2. Facilities that develop test strategy (as expressed in test plans) to satisfy either plant-specific or generic qualification requirements. This includes test laboratories, NSSS vendors, manufacturers, and consultants.

3. Facilities that perform qualification tests. This includes testing laboratories, NSSS vendors, and manufacturers.

There are some broad inspection questions that are useful probing questions for each type of facility. These are:

Facilities that generate qualification requirements and review qualification submittals:

1. Did the A/E specify through purchase orders and other specifications that quality requirements did apply to vendor qualification activities?

2. Did the A/E specify through purchase orders and other specifications the normal and abnormal environmental parameters to which the safety-related component must be qualified?

3. Did the A/E specify through purchase orders and other specifications the performance requirements and functional acceptance criteria to be employed during qualification testing or analysis?

4. Did the A/E during its review of qualification documentation assure that required performance and functional acceptance criteria were satisified?

5. Did the A/E during its review of qualification documentation assure that normal and abnormal environmental parameters were enveloped or satisfied by the qualification test parameters?

6. Did the A/E during its review of qualification activities or documentation insure that appropriate quality standards as specified by the purchase order were being implemented or had been implemented?

Facilities Preparing Test Plans:

1. What are the responsibilities assumed by the design facility?

2. During the review of the facility's test plans and reports, did you discover instances suggesting inadequate training of the staff?

3. Does the staff adequately incorporate codes, regulatory requirements, etc., into its test plans?

4. Does the test plan's acceptance criteria, environmental conditions, etc., adequately reflect the applicable specifications and equipment use conditions?

5. Is there an adequate and auditable review process to insure the correctness of the test plan (strategy, calculations, etc.)?

6. Are deviations and anomalies during testing reviewed by the test sponsor (customer or design facility) to assure that these deviations or anomalies do not impact test strategy conclusions?

7. Are the test plans employing current state-of-the-art qualification techniques?

Test Facilities:

1. What are the responsibilities assumed by the test facility?

2. Is the staff adequately trained? (i.e., was there evidence of inadequate training of the staff?)

3. Does the test facility adequately incorporate test plan requirements into test procedures?

4. Are the test facilities adequate to perform those portions of the qualification tests for which it accepts responsibilities?

5. Are the test procedures and results adequately documented? (Including deviations and anomalies).

6. Is there an adequate and auditable review process to insure that testing is being properly performed and documented?

Now we want to discuss qualification and documentation practices requirements. There are three basic concepts required by IEEE Std. 323-1974 and 10 CFR 50, App B. These are:

1. The qualification documentation must be in an auditable form that allows verification by competent personnel other than the qualifiers.

2. Qualification testing is different than research testing. As a design verification process, qualification testing requires a pre-test, documented plan that describes the required tests and provides an auditable link between the specifications and the expected test results.

3. The purchaser shall perform reviews and audits to insure the adequacy of his purchased product.

These three requirements help insure quality in an environment of proprietary technical issues, manufacturing profit motives, and lack of independent, anonymous peer review. Let us examine the first two of these concepts further.

Auditability:

Section 4 of IEEE Std. 323-1974 discusses the issue of auditability:

"With all qualification methods, the end result must be documentation that must demonstrate the equipment's adequacy to perform its required function. The documentation must be in a form that allows verification by competent personnel other than the qualifiers and should contain the performance requirements, the qualification method, results, and justifications."

Section 6.3.1.1 elaborates on auditability during its discussion fo the test plan:

"The plan should contain sufficient detail to describe the required tests and provide an auditable link between the specifications and the test results. Auditable link means that the plan should provide proof that the test method used was adequate, as this is not always discernable from the test results."

Section 8 provides documentation requirements. It states:

"The qualification documentation shall verify that each type of electric equipment is qualified for its aplication and meets its specified performance requirements. The basis of qualification shall be explained to show the relationship of all facets of proof needed to support adequacy of the complete equipment. Data used to demonstrate the qualification of the equipemt shall be pertinent to the application and organized in auditable form."

IEEE Std. 323-1974 also provides guidance for the contents of a qualification file. For example, when type testing is the basis of qualification, the type test data shall contain:

(1) The equipment performance specifications (Section 6.2)
(2) Identification of the specific feature(s) to be demonstrated by the test
(3) Test plan (Section 6.3.1.1)
(4) Report of test results
The report shall include:
(a) Objective
(b) Equipment tested
(c) Description of test facility (test setup) and instrumentation used including calibration records reference
(d) Test procedures
(e) Test data and accuracy (results)
(f) Summary, conclusions, and recommendations
(g) Supporting data
(h) Approval signature and date

Test Plans:

IEEE Std. 323-1974 indicates that the first step in the test procedure is the preparation of the test plan.

"The plan should be compatible with the equipment specification and should contain sufficient detail to describe the required tests and provide an audiable link between the specifications and the test results. Auditable link means that the plan should provide proof that the test method used was adequate, as this is not always discernable from the test results."

IEEE Std. 323-1974 provides the following content requirements for the test plan.

(1) Equipment descriptions
(2) Number (quantity) of units to be tested
(3) Mounting and connection requirements
(4) Aging simulation procedure
(5) The service conditions to be simulated
(6) Performance and environmental variables to be measured
(7) Test equipment requirements including accuracies
(8) Environmental, operating, and measurement sequence in step-by-step detail
(9) Performance limits or failure definition
(10) Documentation (Section 8.3)
(11) Statement of nonapplicable portions of the specification
(12) A description of any conditions peculiar to the equipment which are not covered above, but which would probably affect said equipment during testing

Documentation:

Were the documentation requirements of IEEE Std 323-1974 achieved? Specifically, does the documentation file include test plans, test procedures, a list of equipment using including accuracy and calibration information? Does the qualification file clearly identify all deviations and nonconformances? Were raw data sheets dated and signed by whoever filled in the data? Does the test plan meet the documentation requirements of the relevant section of IEEE [illegible]1974? Are the number of specimens to be tested clearly ide[illegible]ed in the test plan?

Does the documentation file show evidence of failures that were ignored in the qualification report?

Was the documentation reviewed and approved?

Did revisions to test plans and test procedures receive the same review process as the original?

Some Other Issues:

- Make sure the test plan gives a detailed description of the test specimen, including its materials, parts and subcomponents.

- Make sure that all interface and connection details are provided in the test plan.

- Make sure that the same test specimen is used for all phases of the test plan.

- Make sure that the test specimen is typical of standard production items.

INSPECTION QUESTIONS

Let us summarize some questions that could help focus a thermal aging inspection.

Request a parts list and drawing for the device. Check that all non-metallic components of the device are identified in the aging analysis. For those components deemed necessary for safety-related function, make sure they were considered in the aging analysis. Were self-heating effects accounted for in the aging analysis? Check the maximum rated temperature for each component and insure that the aging temperature employed during accelerated aging is not higher than this temperature. Check the normal operating temperature given for the device. Is it consistent with process fluids or other environments in contact with the device.

Check a few random activation energy references. Is the degradation mechanism for the component similar to that measured for the activation energy analysis? Does supporting data indicate that the measured activation energy is independent of temperature or was there a strong temperature dependence? If a temperature dependence occurred, were the high or low temperature regimes used to determine the activation energy? When literature references are employed as a basis for estimating generic activation energies, is a list of literature references supplied? From the range of possible values was the lowest value chosen as a basis for qualification? Does a test laboratory or manufacturer consistently employ the same literature reference for the same generic material? When analysis is employed to argue component similarity (and hence qualification by similarity) did the analysis consider component lifetime as well as component activation energy?

Verify the aging calculation by checking the mathematics. Make sure that the intended qualified life is clearly stated and is consistent with stated maintenance requirements.

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: EQUIPMENT QUALIFICATION SEMINAR PRESENTED AUGUST 26-28, 1987, 93 pages

DOCUMENT DATE: ______________

DOCUM[illegible] RECEIVED FROM: N. MERRIWEATHER (WORK FILES)

TYPE OF DOCUMENT: SEMINAR NOTES

RESPONSIVE TO ITEM NO: 39

E[illegible]MPTION CLAIMED: NO

YES - ______________

39-G

EQUIPMENT QUALIFICATION SEMINAR

Sponsored by:

U.S. Nuclear Regulatory Commission

Presented by:

U.S. Nuclear Regulatory Commission
and
Sandia National Laboratories

August 26-28, 1987

Albuquerque, New Mexico

Sandia National Laborat

Technical Review of EQ Files

Overview

Environmental

- --Aging
  - --Thermal
  - --Radiation
  - --Operational
- --Seismic (will not be covered)
- --Accident
  - --Radiation, beta and gamma (covered with radiation aging)
  - --Steam
  - --Chemical Spray
- --Post-accident
- --Submergence

Assessment of the adequacy of the above requires additional information as follows:

- --Functional performance requirements and data
  - --Accuracy requirements and data
  - --Insulation resistance data, if needed
- --Qualification basis
  - --NUREG-0588 Category I or II
  - --DOR Guidelines
  - --10CFR50.49
- --Similarity
- --Margin

A simple (and perhaps idealistic) interpretation of qualification which envelops virtually all technical qualification problems is as follows:

Testing, analysis, or operating experience data from identical or similar equipment which verifies that the equipment is capable of meeting its functional performance requirements in all environments to which it might be exposed.

Aging

Objective: to put equipment in its end-of-qualified-life state

Thermal Aging

Usually established by Arrhenius plot or calculations

Arrhenius equation:

$$\frac{t_1}{t_2} = \exp\left[\frac{E_A}{k_B}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

T = temperature in degrees Kelvin (K)
t = time (any units)
E_A = activation energy (eV)
k_B = Boltzmann's constant (8.61×10^{-5} eV/K)

How do we determine activation energy?

--Put samples in aging ovens at various temperatures.
--Periodically remove samples and measure degradation in some property (tensile elongation, dielectric strength, etc.).
--Choose some "standard" of degradation, e.g. 50% of the original value, and find the time to that level of degradation at each temperature.
--Plot log(t) vs 1/T (absolute temperature) for the chosen endpoint. Other "standard" endpoints may also be plotted.
--Activation energy is the slope of the resulting line times Boltzmann's constant if the line is very nearly linear, indicating the sample degradation is dominated by a first-order chemical reaction.

The Appendix gives values of activation energy for many materials from EPRI NP-1558 and may be used for general guidance.

Example plots (from Rockbestos) are shown on the next two pages.

Relationship of Activation Energy and Life

--Activation energy does <u>not</u> give any information about material life.

Example: A claim that because a material has a high activation energy, it has a long life is <u>not valid</u>.

Activation energy measures the amount of <u>acceleration</u> that occurs when a material is aged at a higher temperature.

NOTES FOR TABULATED ACTIVATION ENERGIES

Notes:

1. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). No impregnate.
2. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). Impregnated.
3. Encapsulated with B staged aromatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy transfer molded). No impregnate.
4. Encapsulated with B staged aromatic amine cured bisphenol A epichlorhydrin epoxide (epoxy transfer molded). Impregnated.
5. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot melt). No impregnate.
6. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot melt cast). Impregnated.
7. Encapsulated with modified anhydride cured bisphenol A-epichlorhydrin epoxide. No impregnate.
8. Encapsulated with mixed anhydride cured epoxy novolac. No impregnate.
9. Failure criteria: cracking of insulation to expose conductor, dielectric breakdown leakage current > 300 μA at 3000 V. All specimens tested to failure.
10. Failure criterion: voltage stress of 3000 volts held for 15 seconds at 100% R.H. All specimens tested to failure.
11. Based on graph of log (mean time to failure) vs. 1/T.
12. Failure criterion: 3 A drawn at rated voltage. All samples tested to failure.
13. Burned in @ 125°C, then powered during life testing @ 250°C. Main failure mode was high leakage currents.
14. Calculated from Arrhenius-type plots.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Alkyd, Grade 1500	1.71	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Alkyd, Grade 1500	1.14	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Alken-imide, irradiated, insulation, 20 gauge wire	0.88	461	MIL-W-81044/17A. Mean time to failure. Notes 9 and 14.
Aromatic polyimide, insulation, 20 gauge wire	1.29	461	MIL-W-81381/12. Mean time to failure. Notes 9 and 14.
Butyl	1.08	603	40% loss of elongation. See Note 14.
Capacitors, chlorinated diphenyl. No stabilizers.	1.17	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl. 0.5% anthraquinone	1.53	566	DC life. Stressed at 1000 volts per mil. See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Diode, silicon, 1N673 and 1N696	1.80	339	50% failure. See Note 14.
Diodes, silicon, p-n-p-n	1.41	340	
Diodes, silicon, varactors	2.31-2.38	340	
Diodes, others	1.13-2.77	340	
Diodes, varactors	2.31-2.38	340	
Ethylene propylene, No. 8 lead wire with paper separator	0.71	374	See Note 14.
Ethylene propylene	1.28	51	20% loss in [illegible]ngation. See Note 14.
Ethylene propylene base insulation	1.05	603	40% loss of elongation. See Note 14.
Ethylene propylene, No. 18 lead wire	0.90	374	Estimated average life. See Note 14.
Ethylene propylene, solid —with paper separator	0.70	374	10,000 h life @112°C
Ethylene propylene, solid	0.95	374	10,000 h life @132°C
Enamel, plain, insulation on magnet wire	0.35	610	See Notes 3, 11 and 14.
Enamel, plain, insulation on magnet wire	0.64	610	See Notes 2, 11 and 14.
Enamel, plain, insulation on magnet wire	1.61	610	See Notes 1, 11 and 14.
Enamel, plain, insulation on magnet wire	0.38	610	See Notes 4, 11 and 14.
Enamel, plain, insulation on magnet wire	0.45	610	See Notes 5, 11 and 14.
Enamel, plain, insulation on magnet wire	0.28	610	See Notes 6, 11 and 14.
Epon 828 (Shell Chemical)	1.34	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Epoxy (epoxide film), insulation, magnet wire	0.71	368	See Note 14.
Epoxy, Grade 2000	0.98	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Microcircuits, CMOS type CD 4024A	1.0	795	25h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS type CD 4013A	1.1	795	42h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS, type CD 4011A	1.4	795	90h @ 250°C = 50% failure. See Note 13.
Microcircuit, CMOS 4007 freak pop.	0.9	517	
main pop.	1.3	517	
ML #18 twist pairs	1.43	610	See Notes 7 and 11.
ML #33 coils	1.15	610	See Note 8. Failure criteria was shorted turn, open circuit and/or 2500 volt hipot failure of coil.
ML #18 twist pairs	2.44	610	See Note 8.
Mylar film	1.18	589	Data based on 50% electric strength failure. See Note 14.
Neoprene	0.87	401	70°C - 130°C.
Nitrile	0.86	401	70°C – 100°C.
Nyleze insulation on magnet wire	0.57	610	See Notes 6 and 11.
Nyleze insulation on magnet wire	0.99	610	See Notes 1, 11 and 14.
Nyleze insulation on magnet wire	0.75	610	See Notes 2, 11 and 14.
Nyleze insulation on magnet wire	0.68	610	See Notes 3, 11 and 14.
Nyleze insulation on magnet wire	0.59	610	See Notes 4, 11 and 14.
Nyleze insulation on magnet wire	1.04	610	See Notes 5, 11 and 14.
Nylon 6/6, glass-reinforced	1.14	530	Tested at 205 and 255°C. 50% reduction in tensile strength. See Note 14.
Nylon 6/6, glass-reinforced	1.29	530	Tested at 140 and 150°C. 50% reduction in tensile strength. See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyester, amide-imide overcoated, wire, twisted pairs	1.25	943	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating varnish	1.26	832	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating varnish, in motorette systems	1.66	832	See Note 14.
Polyester-overcoated, unvarnished twists of magnet wire.	1.44	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.67	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.86	832	See Note 14.
Polyester, phenolic varnished, magnet wire.	1.04	832	See Note 14.
Polyester resins (unjelled) Hetron 24505, 853, 354 and Maro 670.	0.87	358	
Polyester, unvarnished, magnet wire.	1.00	832	See Note 14.
Polyethylene, cross-linked	1.13	603	40% loss of elongation. See Note 14.
Polyethelene, cross-linked	1.23	51	20% loss in elongation. See Note 14.
Polyethylene, 0.92 density	1.15	973	t_{10} induction periods. See Note 14.
Polyethylene, low density (below 97°C)	1.51	973	Extrapolated induction periods. See Note 14.
Polyethylene, 0.96 density	1.14	973	t_{10} induction periods. See Note 14.
Polyethylene, low density	1.35	973	(Above 110°C) extrapolated induction periods. See Note 14.
Polyethylene, linear	3.10	537	10% weight loss in vacuum. See Note 14.

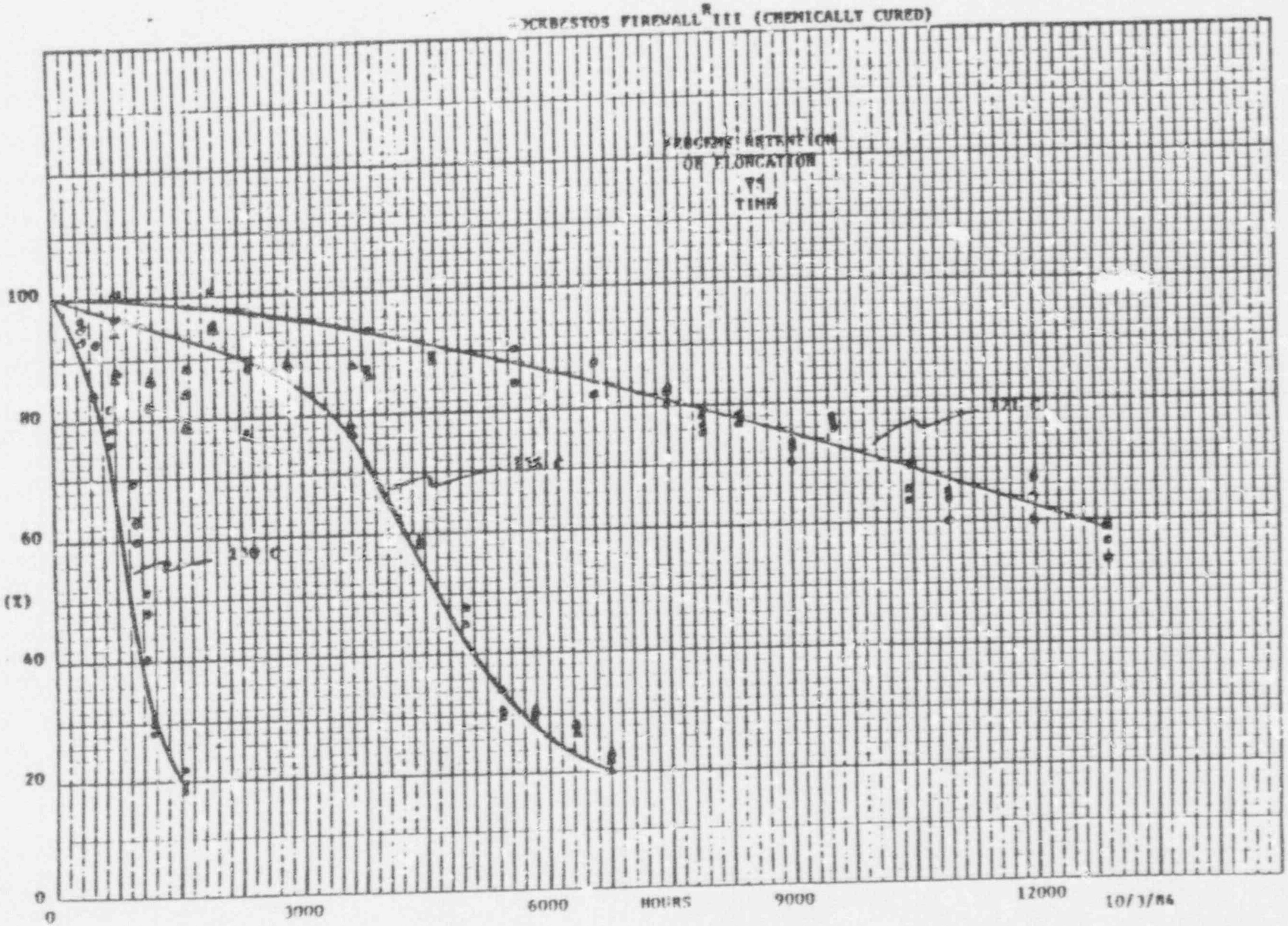
Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polypropylene, isotactic	1.13	973	t_{10} induction periods. See Note 14.
Polyalkene – polyvinylidene fluoride, irradiated, insulation, 20 gauge wire.	1.10	461	MIL-W-81044/9. Mean time to failure. See Notes 9 and 14.
Printed circuit board material ($^1/_{32}$ in.), NEMA G-10 and FR-4	1.05	717	50% retention of electrical strength. See Note 14.
Printed circuit board material ($^1/_{32}$ in.) NEMA G-10 and FR-4	1.49	717	50% retention of flexural strength. See Note 14.
Polyimide, aromatic, TFE-banded and coated insulation, 20 gauge wire.	1.57	461	Meantime to failure. See Notes 9 and 14.
Polymethylmethacrylate	0.34	890	
Polytetrafluoroethelene	0.43	890	
Polytetrafluoroethylene	3.29	537	10% weight loss in vacuum. See Note 14.
Polythermaleze, heavy, insulation and 3M 241 epoxy encapsulant on solenoid coil.	0.95	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation and Acme 4027-A epoxy encapsulant on solenoid coil.	0.92	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 1 and 11.
Polythermaleze insulation on magnet wire.	0.96	610	See Notes 2 and 11.
Polythermaleze insulation on magnet wire.	1.56	610	See Notes 3 and 11.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 4 and 11.
Polythermaleze insulation on magnet wire.	0.98	610	See Notes 5 and 11.
Polythermaleze insulation on magnet wire.	0.75	610	See Notes 6 and 11.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyvinyl formal, impregnated with phenolic type varnish, magnet wire.	1.03	832	See Note 14.
PVC-nylon insulation, 20 gauge wire	1.40	461	MIL-W-5086/2. See Notes 9 and 14.
PVC, irradiated, insulation, 20 gauge wire.	0.99	461	See Notes 9 and 14.
Resin-mica insulation, solventless	0.70	179	Loss factor in stator coils during 10-year field service increased in accordance with Arrhenius model to a peak.
Semiconductor devices, silicon.	0.9-1.4	86	Predominant value – 1.1 eV.
Silicon 6 [illegible] 0-6 (Dow Corning)	1.14	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Silicone, modified, wire enamel on copper without varnish.	1.56	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on copper with silicone varnish.	1.61	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on aluminum without varnish.	1.46	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicon transistors and integrated circuits	1.1	184	Testing of transistors and integrated circuits based on Arrhenius model.
SML insulation and Jones-Dabney epoxy encapsulant.	0.72	320	See Note 14.
Termination, tinned round wire (Sn, Sn + SnPb, Au, Ag)	0.77	69	Present aging relation: 16 h @ 155°C = 5 yr @ room temp. Recommended relation: 4 h @ 155°C = 5 yr @ room temp. Failure caused by: high temperature, high humidity, sulfur dioxide.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Transistors, germanium @ 60°C.	0.99-1.26	136 (Appendix)	
Transistors, germanium	0.17	236	Near and below room temperature
Transistor, germanium, ungettered	0.88	340	
Transistors, germanium, gettered with vycor or molecular sieve	1.24	340	
Transistor, Si mesa, 2N269 (1961)	0.38	677	Conditions not specified.
	0.58	677	Constant stress.
Transistor, Si mesa, 2N560 (1959)	1.12	672	
(1960)	1.50	672	
Transistor, Si mesa, 2N1051 (1960)	1.12	671	
Transistor, modern submarine cable	1.4	129	
Transistors, MOS	1.2	129	
Transistors, MOS	1.10	157	Median life for failure criterion of 1.0-V shift. See Note 14.
Transistors, MOS	1.10	157	Median life for failure criterion of 0.5-V shift. See Note 14.
Transistor, power, MSC 1330	0.81	125	Median time to failure. See Note 14.
Transistors, Si main pop. (1960)	1.02	340	
Transistor, Si planar, BFY 33 (1969)	1.12	235	
Transistor, Si planar, 4A-2(1967)	1.18	675	Step stress.
(1967)	1.50	675	Constant stress.
(1963)	1.29	676	Constant stress.
Transistor, Si, p-n-p-n	1.65	340	
Transistors, silicon, (All)			
—before wearout	1.12	235	
—at wearout	1.46	235	
Transistor, silicon, bipolar	1.02	340	With surface inversion failures.
Transistor, silicon, bipolar	1.02-1.04	340	With Au-Al bond failures.

KEL-7600

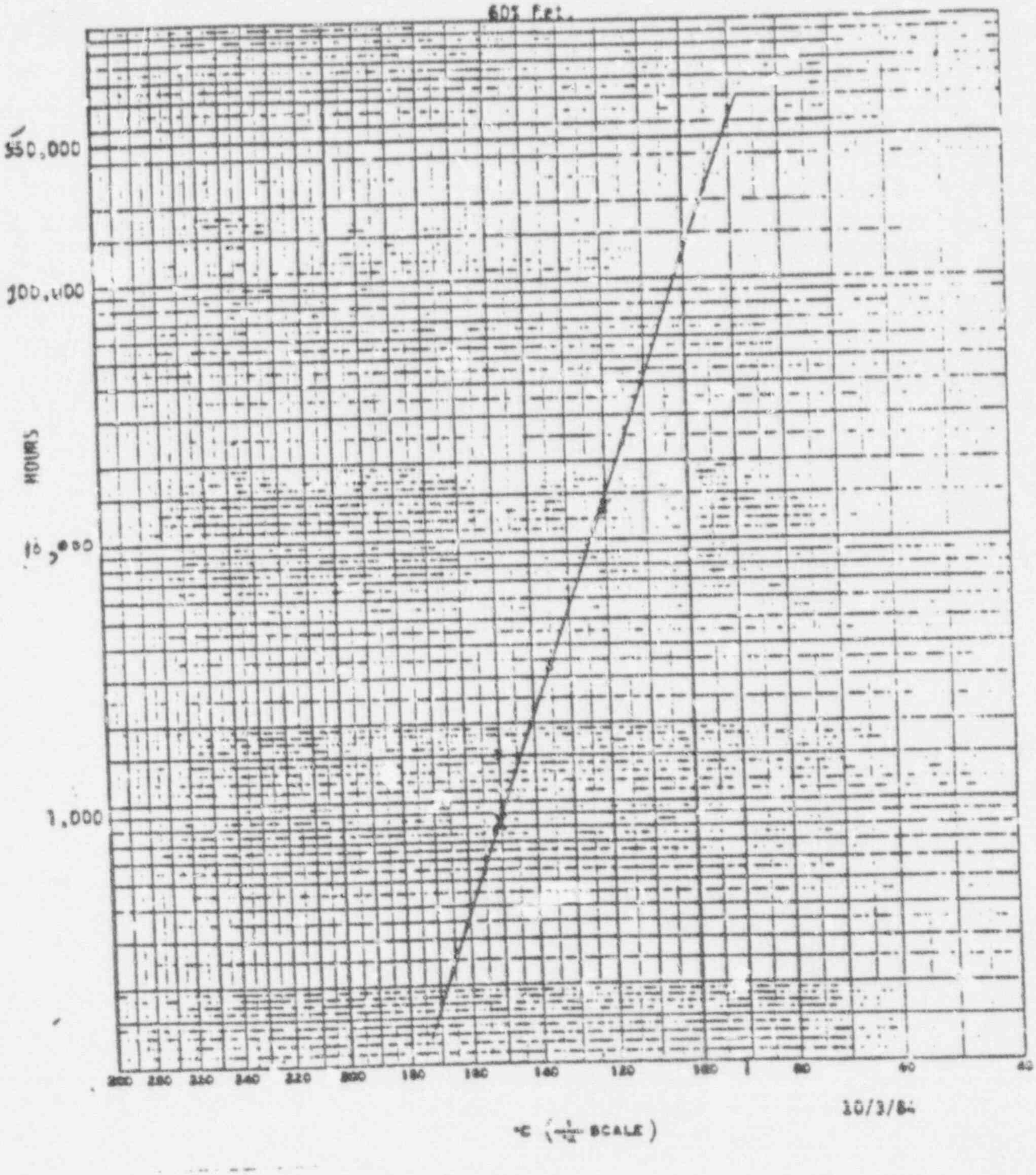
ROCKBESTOS FIREWALL[R] III (CHEMICALLY CURED)



KXL-7600

$\ln y = 15{,}564 \left(\frac{1}{K}\right) - 29.9439$

60% Ret.



Example (Rockbestos data): 825 hr @ 150°C, 4300 hr @ 136°C, and 12600 hr @121°C all represent the same amount of elongation degradation, i.e. to 60% of the original value. The activation energy relates the three different times at temperatures as well as relating similar times/temperatures for any other chosen amounts of degradation.

End-of-life is determined by a criterion which puts a limit on how much a material property can degrade before the material would no longer be capable of performing its intended function. Measures of end-of-life for a cable might be when it can no longer maintain dielectric strength, when its insulation tensile elongation has degraded to a value where the cable is too brittle for handling, or any other criterion one might have for a given application. The major point is that the end-of-life definition is largely determined by the application. The true measure of end-of-life for nuclear applications is when a material or device is no longer capable of performing its intended function in an accident environment for the amount of time required. However, this criterion is not generally used by manufacturers (for practical reasons). The typical approach of a manufacturer is to first determine some set of service conditions (typically some enveloping conditions), the activation energy of the materials involved, and the desired qualified life of the device (often 40 yr, but may be less); next, an artificial aging temperature is chosen based on experience, material limitations, and practicality; finally, using the Arrhenius equation, the artificial aging time is calculated based on the material with the limiting (lowest) activation energy.

Why is this approach acceptable?

This approach causes the material to be in a condition "equivalent" to if it were naturally aged in the plant at the service temperature for its desired qualified life. After other aging, the material is accident tested and checked for functionality. If it functions, the material must have been at some point less than or equal to its true end-of-life for the given application, i.e. in all probability, more aging could have been performed successfully. Conversely, if the material fails, it may have been overaged and may not be able to meet the desired qualified life (note that many other effects, unrelated to thermal aging, could have caused the failure). In addition, overaging of certain materials in the device might cause failures as described below.

Since activation energies can vary widely, the aging of some parts of the device will be accelerated more than the aging of other parts, causing the former to be aged to much greater lifetimes than the desired qualified life. In some cases, this overaging can cause failures of the device which may not be representative of real life aging failures. Different techniques have been used to limit overaging, with some examples as follows:

--Preaging of materials that have low activation energy prior to final assembly of the device with subsequent aging of the complete device.

--Replacement of high activation energy materials at an appropriate time during aging so that they will be aged to the correct qualified life.

NOTE: Most manufacturers do not wish to disturb seals or gaskets used on a device, which can limit the usefulness of the above methods in some cases.

--Selecting a shorter qualified life for the overall device, but requiring replacement of the subcomponents with the lowest activation energies at appropriate intervals.

NOTE: It must be emphasized that the above does not imply that the materials with low activation energies are necessarily anywhere near their true end-of-life, only that the aging performed is insufficient to demonstrate a longer qualified life.

In many cases, none of the above techniques are used and the overaged parts are used throughout the rest of the test sequence.

Other notes on thermal aging:

--Some materials may exhibit non-Arrhenius behavior.

--10°C rule may also be used, i.e. for every 10°C rise in temperature, the life decreases by a factor of 2. However, this method may be somewhat less precise than the Arrhenius method, and therefore it is used sparingly. It may also be modified, to say a 7.3°C rule, based on specific material data.

--In some cases, a utility might use a number of different normal aging environments to cover various operating conditions of the plant when the temperatures are different. In effect, a summation procedure is used in the calculation of qualified life and the Arrhenius equation is modified slightly. This approach is often used if the testing done does not support a qualified life at some enveloping temperature.

--The DOR Guidelines contain the least strict thermal aging requirements. Section 5.2.4 has been interpreted to mean that in virtually all cases, analysis and/or separate effects tests are permissible for thermal life calculations. When thermal aging was not included in the test program, there is no real basis to define end-of-qualified-life in terms of a measurable parameter. Consequently, utilities may choose a definition for end-of-qualified life which will result in a desired qualified life. In general, a basis of below 50% retention of a given property would need good justification.

--The uncertainty associated with the Arrhenius calculations should be recognized and understood. For example, consider an aging time of 100 hours, an aging temperature of 130±3°C, an ambient temperature of 50±5°C, and an activation energy of 1.0±0.1 eV. The range of potential lives from this data is from 3.52 years to 68.6 years! Normally, the life should be determined in a conservative fashion, but this example demonstrates that even slight variations in parameters can make extreme differer 'es in qualified life. The reason is, of course, that the exponential in the Arrhenius equations greatly magnifies uncertainty.

Aging and Accident Radiation

Normally, the total integrated dose (TID) of radiation (aging + accident) is applied at one time using a fixed dose rate which is much higher than the normal aging dose rate and may be on the order of the peak accident dose rate. This type of exposure uses an equal-dose-equal-damage assumption, meaning any possible dose rate effects are neglected (except that margin might be added to the TID to account for dose rate effects).

Applying the total dose at one time at a fixed dose rate is consistent with IEEE 323-1974 and IEEE 383-1974 (for cables). IEEE 383-1974 does state that the dose rate should be less than 1 Mrad/hr for insulating materials. 10CFR50.49 specifically requires consideration of dose rate effects when establishing radiation service conditions. The DOR Guidelines do not require consideration of dose rate effects.

The following materials have been demonstrated to have some dose rate effects:

Ethylene Propylene Rubber (EPR)
Polyvinyl Chloride (PVC)
Low Density Polyethylene (LDPE)
Chlorosulfonated Polyethylene (Hypalon)
Chloroprene

For these materials irradiated to a given total dose, the amount of degradation tends to increase as the dose rate is lowered (up to a point, depending on the given material).

In addition, 10CFR50.49 and NUREG-0588, Category I qualifications are required to consider synergistic effects (dose rate effects may be thought of as one type of synergistic effect). Materials that have been demonstrated to show significant synergistic effects between thermal and radiation aging are as follows:

Low Density Polyethylene
Polyvinyl Chloride

For these later two materials, simultaneous radiation and thermal aging is much more severe than sequential aging. Radiation followed by thermal is best if sequential testing is employed. Both of the above materials are in very limited use inside containments and in virtually all cases where they are used, qualification is to the DOR Guidelines, which does not require consideration of synergistic effects. In these cases, we have to rely on some sort of maintenance/surveillance to detect severe degradation. However, we don't really know what parameters are important in such a program... Current Sandia research is addressing this question.

Beta-Gamma Equivalence

All regulations support using a gamma source to simulate both the beta and gamma radiation. Beta is considered important for exposed materials (primarily cables). Most organic materials other than cables are well shielded from beta radiation, which has very little penetrating power.

Few significant problems have been found in this area. Even when beta radiation is not well addressed in a file, the utility can usually make valid arguments for neglecting its effects.

One possible sticky point: taking credit for beta shielding by a cable jacket when the integrity of the cable jacket is not verified at the end of the test.

Example: In the Rockbestos tests, neoprene jackets were cracked enough to see the insulation on the cables below, but this is not reported in the qualification test report because Rockbestos does not claim any credit for the jacket. One utility, not knowing about the cracked jackets, took credit for the jacket as a beta radiation shield.

Operational Aging

--Generally cycle devices a given number of times
  Only necessary if some failure mode can be reasonably postulated based on cycling. Examples: cables don't really need to be cycled, but solenoid valves should be cycled.

--No major problems known in this area.

Seismic

--Not covered by environmental qualification.

Accident Simulation

Steam Exposure and Chemical Spray

All regulations require steam testing if equipment is to be exposed to a steam environment. This is the one area where even the DOR Guidelines are fairly rigid, stating the following:

"The choice of qualification method employed for a particular application of equipment is largely a matter of technical judgement based on such factors as: (1) the severity of the service conditions; (2) the structural and material complexity of the equipment; and (3) the degree of certainty required in the qualification procedure (i.e. the safety importance of the equipment function). Based on these considerations, type testing is the preferred method of qualification for electrical equipment located inside containment required to mitigate the consequences of design basis events, i.e., Class 1E equipment... As a minimum, the qualification for severe temperature, pressure, and steam service conditions for Class 1E equipment should be based on type testing... Exceptions to these general guidelines must be justified on a case by case basis."

Chemical spray is usually included in the steam test if it is a realistic service conditions. This is true even in older tests, although the DOR Guidelines do allow analysis for chemical spray qualification. Few problems have been found with qualification for chemical sprays, although some minor problems have been identified with facilities performing testing, primarily in quality assurance verification that sprays have been properly determined and mixed. The approximate concentrations of chemical reagents to mix IEEE 323-1974 standard chemical spray is as follows (IEEE 323-1974 spray often used as an enveloping condition):

17.3 g/l of H_3BO_3
10.7 g/l of NaOH
10.1 g/l of $Na_2S_2O_3$ OR 15.2 g/l of $Na_2S_2O_3 \cdot 5H_2O$
NaOH to make pH of 10.5 at 77°F

Steam testing is an area where many problems have been identified:

--Failure to perform a steam test on a configuration similar to the installed configuration (similarity/installation discussion later).
--Failure to monitor appropriate functional parameters during the steam test (more discussion later).
--Failure to envelop required accident parameters.

Example: Namco limit switches were tested with cable leads in sealed conduit such that no moisture could enter the limit switch through the conduit. An acceptable installation is thus to use a conduit seal to prevent moisture entry, but seals may not always be used.

In some cases, deviations may be successfully justified. Example: A thermal lag analysis may be used to show that a short duration temperature transient not enveloped by the test actually results in lower peak temperatures inside a device than does the testing performed over a much longer period.

Example: It is often possible to argue that the orientation of a device is not important during a steam test, such as for a pressure transmitter that is essentially sealed from the steam environment by gaskets or "o"-rings. This argument would perhaps be more difficult for terminal blocks or motor operators, whose orientations may be more critical during testing.

Although failure to envelop required accident parameters seems rather straightforward, it may be complicated by several factors. Rarely will a utility have non-enveloping conditions stated on the SCEW sheet without some analysis of why the deviation is acceptable (see thermal lag analysis example above). However, the important part of the review is to make good engineering judgements of the technical validity of the arguments presented and to be able to provide appropriate questions where the arguments appear weak.

Example for discussion: At Oyster Creek, the conduit seals normally required for Namco limit switches (see above example on Namcos) were not used outside containment. Upon questioning the rationale, utility personnel stated that the accident environment at the location of the limit switches (193°F and 100% relative humidity) did not constitute steam service as defined by the DOR Guidelines and hence did not require a steam test. The walkdown inspection revealed that the limit switches were at the lowest point of a run of about five feet of conduit. What do you think?

Discussion of Saturated vs. Superheated Steam

Saturated steam is steam which is at a temperature and pressure where both liquid and vapor can coexist <u>at equilibrium</u>. Some saturated temperature/pressure conditions are as follows:

Temperature (°F)	Pressure (psia)
70	0.363
100	0.950
150	3.722
200	11.53
212	14.70
250	29.82
300	66.98
350	134.5

Relative humidity is the ratio of the partial pressure of water vapor to the saturation pressure of the steam at the given temperature.

Example: A water vapor/air mixture has a total pressure of 14.7 psia. What is the relative humidity if the temperature is 100°F and the vapor has a partial pressure of 0.5 psia (i.e. vapor accounts for 0.5 psia of the total pressure and air accounts for 14.2 psia of the total pressure)?

Solution: The saturation pressure of steam at 100°F is 0.950 psia. Therefore, the relative humidity is 0.50 / 0.95 x 100% = 53%.

Superheated steam is steam that is at a temperature greater than the saturation temperature at the given partial pressure of the steam, or equivalently at a partial pressure below the saturation pressure at the given temperature. In the example above, at 53% humidity, the environment technically includes superheated steam since the partial pressure of the steam (0.5 psia) is below the saturation pressure at the given temperature (0.95 psia)! Similarly, subcooled liquid is at a temperature below the saturation temperature at the given total pressure (total pressure since the substance is in a liquid form). An example of a subcooled liquid is a glass of water which is evaporating.

A relative humidity of 100% implies that the environment includes saturated steam, although at low temperatures, it is usually not thought of as such. The reason is that at low temperatures and 100% humidity, the amount of moisture is much less than at higher temperatures. The absolute <u>amount</u> of moisture is directly related to the partial pressure of the vapor and the <u>probability of condensation</u> is related to the partial pressure of the vapor and the temperature of the surface where the moisture might condense. Condensation occurs if the partial pressure of the vapor is above the saturation pressure corresponding to the temperature of the potential condensation surface.

Example: Will condensation occur from a water vapor/air mixture at 150°F and 40% humidity onto a surface at 100°F?

Solution: The partial pressure of the water vapor is the relative humidity in decimal form times the saturation pressure of steam at 150°F, or 0.40 x 3.722 = 1.5 psia. The saturation pressure corresponding to the temperature of the potential condensing surface is 0.95 psia. Therefore, condensation will occur.

The theoretical sequence of events which occurs to a component when steam is dumped into a closed compartment (such as a containment) is as follows. First, the component is usually at a temperature below the saturation temperature corresponding to the resulting partial pressure of the steam (unless the component has very significant self-heating). Condensation immediately begins on the surface of the component. The maximum temperature of this condensed steam is the saturation temperature of steam at the partial pressure of the ambient steam. Next, as condensation continues and heat is transferred to the component from the ambient steam, the temperature of the component rises until it reaches at least the temperature of the environment. The temperature may increase further if the device generates any internal heat. Finally, at this point, one of two situations occurs: if the device has self heating, it will eventually cause the collected moisture to evaporate; if not, an equilibrium will be attained with liquid on the device in equilibrium with the surrounding environment.

In reality, the sequence will not occur exactly as described above. Many interacting factors will govern exactly what happens. Some important complicating effects are those of chemical sprays and contamination in the plant (dust, chemical residues, rust, etc.) which will tend to keep more moisture on equipment.

Hopefully, the above will provide some insights into what a "steam" environment really is and some of the very basic mechanisms of steam behavior.

Post-Accident

The regulations generally require that equipment be qualified for the time duration that they need to function, plus margin. The staff position has been that post-accident acceleration using Arrhenius analysis is normally acceptable as long as the acceleration is not excessive (not easily defined, of course). The DOR Guidelines tend to be most permissive in that they only require qualification up until the time that the accident conditions have essentially returned to pre-accident values, and they also specifically allow thermal aging-type calculations to justify even shorter tests.

Even though the post-accident acceleration has typically been deemed acceptable, there are some assumptions made in the analysis that are significant and may be non-conservative in some cases. One example is that using thermal aging analysis for post-accident qualification assumes that the only failure mechanism is thermal age related. This approach discounts long-term moisture related failures to a large extent, should they exist.

In general, the transient part of the accident may not be accelerated or used for acceleration; only the steady state portion of the post-accident exposure should be accelerated. However, calculations which include credit for the transient portion of the accident and demonstrate very long post-accident qualification are generally not questioned (i.e. where the steady state portion alone could easily be shown to be sufficient by itself).

Submergence

The regulations all support actual submergence testing to qualify components which may become submerged. Specifying saturated steam during accident testing is generally not considered adequate for submergence qualification.

Example: A clear case where saturated steam would be insufficient is when testing terminal blocks. For many applications, the blocks can be qualified for saturated steam, but invariably, terminal blocks will fail when submerged.

From a technical standpoint, it should be possible to qualify some types of equipment for submergence based on saturated steam testing. Specifically, the following points would need to be addressed:

--The device would have to be sealed from the environment by design.
--The qualification report would have to make a clear and convincing argument that no moisture got into the device. A simple visual inspection stating that there was no evidence of moisture intrusion may not be sufficient, although detailed examination results might be more convincing.
--Similar to the above, a valid argument addressing moisture intrusion from interconnections, such as cables, conduit seals, and conduit fittings, would be necessary.
--Verification that the seal materials would not be degraded by the submerged condition.

Examples for discussion:

1) Minco RTDs submergence question at Diablo Canyon.

2) Neutron monitor junction box at Maine Yankee

Functional Performance Requirements and Data

The regulations require demonstration that plant functional performance requirements have been satisfied for the environments in which the device must operate. Many individual instances can be cited where utilities have failed to do this, but they generally fall into one of two categories:

1. The functional performance requirements are not specified adequately.
2. The qualification report and EQ file do not demonstrate that the functional performance requirements have been met, most often during accident conditions.

The first item seems obvious, yet legitimate questions can be asked such as what are the necessary functional performance requirements for a section of cable, which doesn't necessarily have an easy answer. Even further, what is the necessary accuracy for a pressure transmitter used to monitor reactor coolant pressure following an accident and what is the technical basis to support the necessary accuracy? In general, the accuracies should be based on assumptions used in developing the plant safety analysis, but determining the necessary accuracy for a particular instrument is often difficult on this basis.

Let's leave some space here for notes and get some class opinions on the subject of determining instrument accuracy.

In general, power and control devices have somewhat more easily specified performance requirements. For example, a motor operated valve may need to "open or close on demand and remain in the desired position." However, one might ask the following question of a particular test which appeared to demonstrate the above capability:

--Does the motor torque degrade during the accident test? If so, how much, and does this degrade operability of the valve

2

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

in the as installed configuration (e.g. when working fluid interactions with the valve are considered, coupled with degraded torque).

As another example, a solenoid valve might have similar requirements as for the motor operated valve described above. However, one might fail to consider a specification on allowable leakage of the valve. How to determine the allowable leakage may be somewhat difficult, but it should be addressed.

Utilities generally use two different approaches to determine the functional performance requirements. First, based on something, they may determine the necessary requirements for their application and then check that a particular test verifies that the requirements are met. Alternatively, the demonstrated parameters from testing may be evaluated and found to be acceptable. This second method presents somewhat of a direct conflict with IEEE 323-1974, which states in section 6.3.1.1 that the test plan should include "(9) Performance limits or failure definition." However, the staff position has been to accept this latter method of demonstrating functional performance, largely because much testing is done in a generic fashion and in most cases, the functional performance requirements are plant specific.

Interconnecting devices, such as cables, penetrations, terminal blocks, etc. present unique challenges to defining functional performance requirements. What is it that these interconnecting devices must do, exactly? They must transmit current and voltage from one place to another while maintaining the desired characteristics of the transmitted parameters. The first part, that of transmitting current and voltage from one place to another, is usually addressed in any reasonable qualification. The second part is the difficult part. What parameters need to be measured to determine that the desired characteristics of the transmitted current and voltage are maintained? At this point I will defer further discussion to the specific issues sections.

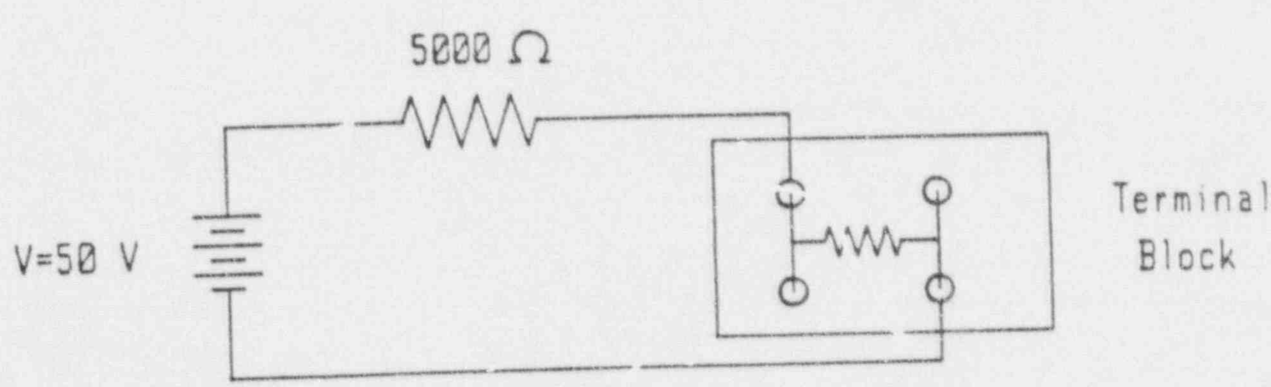
Once adequate and complete functional performance requirements are defined, the second step is to demonstrate that they are met based on the tests conducted. It is easy to envision that the most important time, and indeed, often the most difficult time, for verifying functional performance requirements is <u>during</u> accident environment application. The specimen will usually be inside a test chamber where it is largely inaccessible and the harsh chamber environment makes some types of monitoring difficult. If a good test was conducted and all the pertinent parameters were measured, it is straightforward to compare the specifications to the demonstrated performance. In many cases, however, the performance data during the accident test is not 100% complete. The following give some examples of potentially incomplete data:

--All parameters were not measured during the accident exposure.
--Parameters were not measured at appropriate times.
--The data presented is inconsistent and thus questionable.
--Parameters were not measure over the entire spectrum of instrument operation.
--At the utility level, the test report may not include all data that was taken during the test.

Thus, it is often necessary to use good engineering judgement, experience from similar tests, and insights from other team members to make a determination as to whether the performance requirements have been adequately satisfied.

The individual sections on specific components will provide more insights for component specific functional performance requirements.

Later, we will discuss the related measurements of insulation resistance (IR) and leakage currents. At this point, we will address the question of the relationship between IR and leakage current. In Ohm's law, $V = I * R$, the resistance R (or IR) is assumed to be a fixed value, as for a commercial resistor. On the other hand, leakage current I is directly proportional to applied voltage (with R assumed constant). The applied voltage is the voltage across the resistance R and may vary with varying leakage currents. In the figure below, the voltage applied to the circuit is 50 Vdc. With no leakage current (i.e. $R=\infty$), the voltage applied across R is 50 V, but with a leakage current in the circuit of 9 mA, the voltage applied across R is only 5 V. The corresponding leakage current if the full 50 V were applied would be 90 mA, a significant difference. Thus, it is important to remember that leakage current varies with voltage, but resistance is generally assumed to be independent of voltage. It should be mentioned that some valid arguments do exist to refute that R is independent of voltage, but we will not discuss them here.



Similarity

All the regulations require that qualification be based on either an identical or similar piece of equipment. If qualification is based on a similar piece of equipment, then a supporting analysis is necessary to demonstrate that the tested and installed equipment is indeed similar. This is often necessary since every different model, configuration, and installation cannot be tested practically. Therefore, we have the question, what constitutes a similar piece of equipment? The answer, as so many times before, is not an easy one. Similarity may need consideration of form, fit, function, materials, manufacture, and installation. A very important point is that similarity depends largely on the application. A similarity argument essentially must demonstrate that because one piece of equipment was successfully tested in some environment, another piece of different equipment will also perform its required function in another (possibly different) environment. Consider some examples as follows:

A pressure transmitter with a range of 0-1000 psi is to be qualified based on testing of a pressure transmitter with a 0-10 psi range. Everything is identical about the transmitters except that a different stainless steel bellows is used. The desired qualification environment is the same as the test environment. Are the units similar?

A limit switch was tested using a conduit seal to IEEE 323-1974 conditions (including 200 MR radiation). A plant is using the same limit switch in a radiation only harsh environment (100 MR maximum), but they did not install a conduit seal. Is the tested switch similar to the installed switch?

A whole family of cables is to be qualified based on testing of representative samples. Which cables should be chosen as the representative samples? See Table 1 in IEEE 383-1974 for suggested selection of representative samples. In addition, paragraph 1.3 states that "qualification of on cable may permit extrapolation of results to qualify other cables of the same type, with consideration given to cable dimensions and probable modes of failure."

A terminal block from one manufacturer is to be qualified based on testing done on the terminal blocks of two other manufacturers. All are made of a nonspecific phenolic material. The testing on the two terminal blocks used the IEEE 323-1974 suggested profile (340°F for six hours, etc.). The terminal block to be qualified is used where the peak environment is 225°F for 4 minutes, followed by a decrease to 150°F in 30 minutes and return to the ambient of 90°F after 3 hours. Performance of the tested terminal blocks was quite good, about as expected for terminal blocks in the test environment. Are the blocks similar?

More similarity examples, including discussion of generic materials similarity, will be included in the specific component sections.

Margin

Margin is essentially the difference between the worst case plant conditions and the test conditions. It is applied to account for uncertainties in the qualification process and for normal production variations of equipment. IEEE 323-1974 gives recommended values for margin and they will not be repeated here. A significant point to address here is that of margin in one area "compensating" for lack of margin in another area or in some cases, even lack of enveloping in some areas. My philosophy is that one needs to look at the qualification package as a whole and decide whether the package verifies with reasonable certainty that the equipment will perform its function when required. Thus, my feeling is that some amount of the above is reasonable. However, some points I would carefully consider are as follows:

--A great deal of margin in one area should be used to get a much smaller margin in another area.
--The area lacking some margin or enveloping should be an area where known failure modes of the type of equipment under consideration are not dominant.
--Knowledge of industry qualification experience with the equipment needs to be considered.
--When in doubt, consult with others as appropriate, and when not reasonably sure, err on the conservative side.

Some examples:

--A cable was tested to a demineralized water environment when it is needed in the plant for a more severe chemical spray environment. A successful argument might be that the other parameters are well enveloped, the material the cable is made of is not typically degraded by the chemicals in the spray, and that cable failures in qualification testing are normally unrelated to chemical sprays.

--A solenoid valve was tested to a 300°F/67 psia saturated steam environment for 3 hours and is needed at 320°F/50 psia superheated steam environment for 30 minutes, followed by 30 minutes at 275°F. The above requirements include the suggested 15°F margin. The solenoid valve was thermally aged at 350°F for 7 days prior to steam testing. A successful argument be that the valve was aged at a temperature well above the necessary steam qualification, that there is significant time margin in the test (even though at a reduced temperature level), that the required pressure was enveloped, that the actual required temperature (before margin) is only 5°F above the test temperature, that the actual amount of moisture present is enveloped, and that the temperature/moisture interaction in the steam environment is not a major failure mode for solenoid valves. A similar argument might not work so well if the component were a terminal block used in an instrumentation circuit.

Specific Component Issues

Cables

The following list includes many of the issues identified for cables:

--Utility does not know for sure what cable is installed.
--Utility does not have all installed cable on the master list.
--Utility does not have adequate documentation for qualification.
  --Similarity inadequate (includes generic qualification issues).
  --Functional performance inadequately addressed.
  --Environments not enveloped.

The first two items on the list are related and may be assessed in two major ways. One way to assess what is installed vs. what is on the master list is to look at cable in the plant that is connected to qualified equipment and verify that the cable is on the master list (physical inspection covered elsewhere in the course). In some cases, the cable may not be field identifiable and it is necessary to rely on the second method, examining the plant's quality assurance and installation records to identify cables. In some cases, utilities do not know exactly what cable is installed in what circuits, but they do have an exhaustive list of all cables which might be installed in qualified circuits and they have qualification documentation for all the possibilities. Obviously, this is the less preferable method since any problems identified with a particular cable (either during an inspection or at a future time) are much more difficult to deal with.

The remainder of the list looks very familiar to the items in the earlier definition of qualification given earlier. Cable similarity has been questioned often and in many cases has not been adequately demonstrated. Recently manufactured cable is much less prone to similarity problems because the industry has become well aware of the issues involved. The major problems thus occur with older cables. One of the more controversial issues has been that of generic material qualification, i.e. trying to qualify one manufacturer's cable based on successful testing of a second manufacturer's cable made of the "same" material. In some cases, generic qualification has been accepted to a limited extent, but this hardly means that the staff position is to accept it blindly as some in industry, particularly consultants, might imply. Each case must be carefully evaluated on its own merits. I will attempt to give some insights into what needs to be considered in such a qualification because each case is unique. The following questions should be kept in mind during a review:

--Is the cable inside or outside containment?

--What are the environmental conditions for the cable?
--What are the typical capabilities of the material under consideration?
--How does the local environment compare with typical capabilities of cables in general as well as with typical capabilities of the particular material?
--What similarity information is available for the tested vs. installed cables?
--What type test data is available for the specific material?
--How much can margin in one area compensate for deficiency in another area?

So far, only one instance of generic material qualification for inside containment applications (Ft. St. Vrain) has been accepted, based on special circumstances including virtually no radiation dose and a relatively short accident environment at high temperatures. Several additional cases have been accepted for outside containment based on considerations of the above. The above type of information should be addressed in the qualification package. As is apparent, determining the adequacy of generic qualification can require experience and good engineering judgement. When in doubt, consult with others as necessary.

Many other similarity issues have come up. In general, the utility should have a certificate of conformance from the manufacturer with a statement that the cables are identical or similar to tested cables. If similarity is claimed, the basis should be specified and justified, as necessary. An earlier example gave information on choosing representative samples from a family of cables. Thus, a statement from the manufacturer that the materials and method of construction are the same as tested cable is generally sufficient for establishing similarity unless particular concerns are known for the specific cables. The testing should generally include samples with the minimum thickness of insulation used in the plant. Most recent qualifications will meet these criteria.

Example for discussion: Butyl Rubber. Both Big Rock Point and Quad Cities have butyl rubber cable installed. Both qualifications have been questioned for various reasons.

Discussion:

Other Cable Similarity Concerns

- Certificate of Conformance
- Small Material Changes

— Factor of 2 decrease in IR for 10°C increase in Temperature

Some difficulty may arise in terminology such as if a utility states, for example, that they have Rockbestos Firewall III insulated cable and that testing was also performed on Rockbestos Firewall III insulated cable. In fact, much more specific information is sometimes necessary to establish similarity. Some information will be given in the specific product listing for commonly encountered cable products; in other cases it may be necessary to request vendor catalog information, discuss specifics with the licensee, or consult with appropriate personnel.

The question of adequately addressing functional performance for interconnecting devices was mentioned earlier. The staff position for cables has been different for different types of cable. For instrumentation cables and interconnections, the primary parameter of interest is IR data or leakage current data <u>during</u> the steam/spray simulation. The concern is greatest for devices involving exposed terminals of any kind, such as terminal blocks. However, the staff position has been to require data for any instrumentation interconnecting device exposed to harsh steam environments. Analysis of the effects of degraded IR on instrumentation circuit accuracies has often been neglected by utilities in the past. Two methods may be used to assess the effects: either determine an acceptable IR for the circuits and verify that it is met or verify that the measured values are adequate. The individual sections on specific components will describe the types of analysis for determining potential accuracy degradation from interconnecting devices. In general, for non-coaxial type applications, instrument cable IR of above $10^6\Omega$ for a test length of 10-15 ft can be shown to be acceptable. Coaxial cable applications have special requirements and will be discussed in the radiation monitor section. The major application for coaxial cable inside containment, other than radiation monitors, is acoustic monitors for valve position indication. Specific requirements for these circuits don't seem to be nearly as severe as for radiation monitors, but they have never been as extensively examined; they will not be covered in this material.

Power cable is at the opposite end of applications from instrument cable. The staff position has been that IR measurements are not necessary for power cables if a good test was performed and the cables were loaded with appropriate current and voltage during the test and satisfactorily passed a post-test dielectric withstand test. (In some older qualification tests, the withstand test may not be included.)

Control cable applications, and hence requirements, fall somewhere between power and instrumentation. In some control circuits, IR considerations may become important, although this is rarely the case. Cable IRs above $10^5 \Omega$ for a test length of 10-15 ft _during_ steam testing are generally sufficient. For most outside containment applications, the IR for control cables would not fall to low enough values to cause circuit problems. Hence, in some cases, a test where IRs were not measured has been found acceptable if a good test was performed and the cables were loaded with appropriate current and voltage during the test and satisfactorily passed a post-test dielectric withstand test. For inside containment applications, the IR data would generally be required. In any case, consideration of the environment the cable is expected to survive in is an important consideration.

Several specific areas to be aware of are as follows:

--Scaling of IR data. According to physical laws, if the cable length is increased, its IR decreases. A few manufacturers report IR data using units of Ω-1000 ft, which is the IR of 1000 ft of cable. Most report the IR for the tested length of cable. It is important to recognize that the two may easily differ by nearly two orders of magnitude and that the guidelines mentioned in the above paragraphs refer to tested lengths of cable. In analyzing the effects of degraded IR, the actual installed cable length needs to be considered relative to the tested length. The IR to use in the calculation is found by as $IR_{installed} = IR_{tested}$ x (length tested / length installed). If the IR is given in an Ω-1000 ft basis, then 1000 ft should be used as the length tested. In actual testing, the measured IR is artificially low because of the parallel effects of penetrations and lead wires. Sandia has data over a limited range which appears to support an increase in a calculated value by at least a factor of 2 if the scaling is over a length of at least a factor of 3.

Example: A 15 ft section of cable was tested and had a minimum IR of 5×10^5 Ω. The plant has an installed length of 200 ft. What IR should be used in the circuit calculations?

Solution: The IR equation gives $5 \times 10^5 \times (15 / 200) =$ 37.5 kΩ. However, the length scaling is greater than a factor of 3; thus, the IR may be increased by a factor of 2 to 75 kΩ.

--Failure modes considered. In some cases the utility may only consider certain failures resulting from decreased IR. One common occurrence in consideration of control circuits is to only determine if the IR is low enough to cause fuses to open. In fact, there may be other undesired effects which can occur at much higher IR than that required to open a fuse, such as spurious indication or operation. Some of these will be discussed in other sections.

--Use of post-test IR data in analyses. Where IR considerations are important, it is imperative that IR data <u>during</u> steam/spray exposure be used. The IR almost always recovers after removal of the harsh environment (unless a failure has occurred).

--A rule of thumb is that bulk IR decreases by a factor of 2 for every 10°C increase in temperature when in a thermal-only environment. Decreases at least that large should be expected during steam testing, with higher values possible. This rule may often be used as a basis to assess whether test results are reasonable.

The following list gives some manufacturer's product names along with some information about the product:

--Rockbestos Firewall III and Pyrotrol are product names for chemically cross-linked polyethylene (XLPE) insulation and may use either a hypalon or a neoprene jacket. Pyrotrol is an old formulation; Firewall III has been produced since Pyrotrol and has several different formulations, most with a KXL 760 type designation (one old formulation is KXL 510). The most recent formulation is KXL 760D and is covered by Rockbestos test report QR-5804 (a new report of testing which the NRC closely followed). Most older formulations are qualified by utilities using old test reports (those questioned in IN 84-44) in combination with similarity to tested KXL 760D and possibly other test reports. IN 84-44 allows several methods for dealing with the old questionable test reports including performing additional testing, analyzing the old test reports (to show significant margin to account for possible problems), or obtaining additional test reports from other sources (some Sandia testing has been cited). The Firewall III designation is also used for irradiation XLPE; however, the formulation of irradiation XLPE has not changed over the years to the best of our knowledge. A new test report, QR-5805, covers all irradiation XLPE and this testing was also followed by the NRC.

--Rockbestos Adverse Service Coaxial Cables are available in several different products, the most common being RSS-6-104 and RSS-6-113. These use two insulations, a radiation XLPE insulation and a inner insulation, called either LD or LE. The original (1st generation) coaxial cable was found to not function satisfactorily above about 230°F and is supposed to have been removed from all applications where the temperature could exceed the thermal limitations. The 2nd generation cable used a modified braid angle to prevent the conductor kinking failures of the 1st generation cable. Subsequently, the LD polymer of the 1st and 2nd generation cable was changed to an LE polymer and the new cable is designated 3rd generation. The LE formulations were tested successfully and the results are reported in QR-6802. A similarity analysis was prepared by Rockbestos to qualify the 2nd generation cable based on the 3rd generation cables (the 2nd generation test report is one questioned by IN 84-44). This analysis has been reviewed by the staff and has been accepted at several plants. Production dates for the cables are as follows: 1st generation before 6/8/81, 2nd generation from 8/20/81 to 3/14/83, and 3rd generation since 3/15/83.

--Rockbestos also produces silicone rubber (SR) and ethylene propylene rubber (EPR) insulated cables which have not been retested. Qualification depends on plant specific applications and analysis within the guidelines of IN 84-44.

--General Electric SI-57279 is called Vulkene Supreme SIS and is a XLPE insulated cable. One applicable test report is #F-C4497-2, a Franklin report of 3/77. A letter recently seen at a utility indicated that GE considers standard Vulkene SIS, or SI-57275, to be not qualified. Thus, it is important to distinguish between the two, non-similar formulations. The SI-57275 may possibly be qualified by other test reports to some environments, but GE currently sells only the Vulkene Supreme for nuclear applications. A current question under investigation is what Vulkene cable is used in GE electrical penetrations produced a number of years ago.

--Boston Insulated Wire (BIW) Bostrad 7E cable is an ethylene propylene rubber (EPR) insulated and hypalon jacketed product. Qualification testing is covered by BIW report BIW 915 and an updated version BIW 915A. Both of these reports have been determined to not support IEEE 323-1974 qualification. See Inspection report 99900283/83-02 for more details. This test report has been found acceptable for some applications where the DOR Guidelines apply. Current information indicates that additional testing of the cables has been performed to qualify them to 10CFR50.49 requirements.

--Samuel Moore (Eaton Corp.) Dekorad is an ethylene propylene diene monomer (EPDM)/hypalon layered insulation with a hypalon jacket for instrument applications. Cable testing is reported in an Isomedix test report of June, 1978. Other Samuel Moore cables include Polyset (radiation XLPO) and Elastoset (Flame Retardant EPDM).

--Kerite Corporation high temperature (HT) or high temperature Kerite (HTK) and a flame retardant (FR) compound are used in various combinations for insulations and jackets for power and control cable. Various combinations have been tested, with the control cable giving low IR values.

--Brand Rex produces a XLPE insulated cable with a hypalon jacket. Testing is reported in Franklin Reports series F-C5120- and in report F-C4113 for various applications, configuration, and types of cables.

--Raychem Flamtrol uses an XLPE insulation and has not been produced for quite some time. It is used at a number of plants and qualification should always be to the DOR Guidelines.

--Okonite has a number of different products, including insulations/jackets with trade names Okonite (EPR), Okoseal (PVC), Okoguard (EPR), Okozel (modified ethylene tetrafluoroethylene, or tefzel), Okotherm (SR), Okolon (EPR/hypalon composite), and X-Olene-FMR (chemically XLPE). Okonite did research testing on many products and supplies selected data to customers based on individual needs. Some concern has been noted that only positive results have been given to customers, with no mention of test anomalies or failures on similar or identical cables. The large number of different cable materials indicates that care should be used to ensure similarity of test specimens to installed cables.

A large number of cable types have been identified at only one or two utilities and hence must be carefully evaluated on a case by case basis. The following list gives some of these rare manufacturers/types (for nuclear use), but no attempt is made at describing any in detail:

BIW silicone rubber, Galite, Hatfield, Lewis, Simplex, Plastics Wire and Cable Co., Essex, Times W&L, Rome (Cypress), Tensolite, General, Teledyne, Haveg, Essex, and Harbour.

Some of the above may include manufacturers that are subsidiaries of more common manufacturers or names that have otherwise been obscured.

Some more common manufacturers have had name changes or affiliations which are useful to know. For example, Rockbestos was formerly called Cerro, Continental is a subsidiary of Anaconda, and Rome and Cypress are equivalent.

Electrical Penetration Assemblies (EPA)

As for any other type of equipment, the problems for EPAs fall into categories of similarity, performance requirements, and environmental enveloping. However, concerns over similarity and environmental enveloping have been much less pronounced than for cables. Functional performance has very often been neglected for EPAs, but the required analysis is exactly the same as for cables, terminal blocks, etc. with the EPA simply another parallel resistance in electrical circuits. Since component specific IR effects will be discussed separately for different devices, they will not be repeated here.

The most significant recent similarity issue has been that of butt splices supplied by GE with F-01 series electrical penetrations. As a result of audit findings at Dresden, CECo tested splices at Wyle and found some failed the test. The original issue stemmed from GE supplying nylon-insulated splices from more than one manufacturer, with no specific documentation to establish exactly what was tested nor what was supplied to plants. It should be noted at CECo believes that the connectors are still qualifiable and that the configuration in the Wyle test was overly conservative. Butt splices that were taped successfully passed the qualification test and CECo has taped the splices in both Dresden and Quad Cities.

One concern that has been identified as a result of Sandia testing is that electrical failures of D. G. O'Brien penetrations may occur as a result of moisture intrusion. The moisture barrier, made from a silicone rubber elastomer, tends to undergo major dimensional changes when subjected to compressive loads, especially when also subjected to elevated temperatures. These changes have been observed to cause damage to conductor insulation as well as allowing moisture intrusion. One way to avoid the failures may be to age component parts separately, but separate aging may not be realistic. Consequently, D. G. O'Brien EPAs should be examined carefully.

Terminal Blocks

The generic issues for terminal blocks parallel those for other equipment. In general, I feel that dimensional differences, including the shape of the block and the shapes of convoluted surfaces on the block, are the major factor governing differences in terminal block performance. The major factor for terminal block performance is the ability to carry voltage and current without excessive leakage currents. The major mechanism for terminal block failure in a steam/chemical spray environment is surface leakage currents and/or surface breakdown. The major factor governing the leakage currents seems to be the physical size and detailed shape of the block. This information suggests that the materials of construction have less effect on accident performance than for other types of equipment, as long as severe radiation or thermal degradation has not occurred. In general, phenolics are used for terminal block construction and they are not very age sensitive. Consequently, the major emphasis should be on accident performance. Similarity evaluation should largely be based on dimensional considerations which lead to primary failure modes.

One particular block which has received considerable attention lately is the Marathon 1500/1600 series blocks. The two series are quite similar and have been recently tested by Wyle for CECo to measure leakage currents. The leakage currents reached about 300 mA at 132 Vac and 135 Vdc for four terminal blocks (including a 1600 series) located below unsealed conduit entrances to the top of a NEMA-4 enclosure. The one block (1600 series) not located below the top entrances gave leakage currents below 40 mA at similar voltages. The obvious conclusion is that any top entry conduit usage should be examined carefully and generally discouraged.

The Wyle test has a very subtle, but instructive example of possible improper monitoring of leakage currents in any test. In the figure on the next page, the value of P1 is adjusted to give a loop current of 16 mA during the accident simulation. A simple calculation gives the required value of P1 as 625 Ω. Another simple calculation, assuming a dead short of the terminal block for circuit 1, gives a loop current of 67.2 mA as the maximum loop current. The 500 mA fuse included in this loop can never open as a result of leakage currents on the terminal block! Fortunately, in this test actual leakage currents were monitored. However, if the actual leakage currents had not been monitored, this particular circuit would give no indication whatsoever as to terminal block leakage currents during the accident exposure. This example emphasizes the need to see accurate and complete documentation of test apparatus, particularly when leakage currents are claimed to be monitored via a fuse in the energizing circuit.

In another Wyle test (45603-1) of the same terminal blocks, when power was applied to test specimens following a power

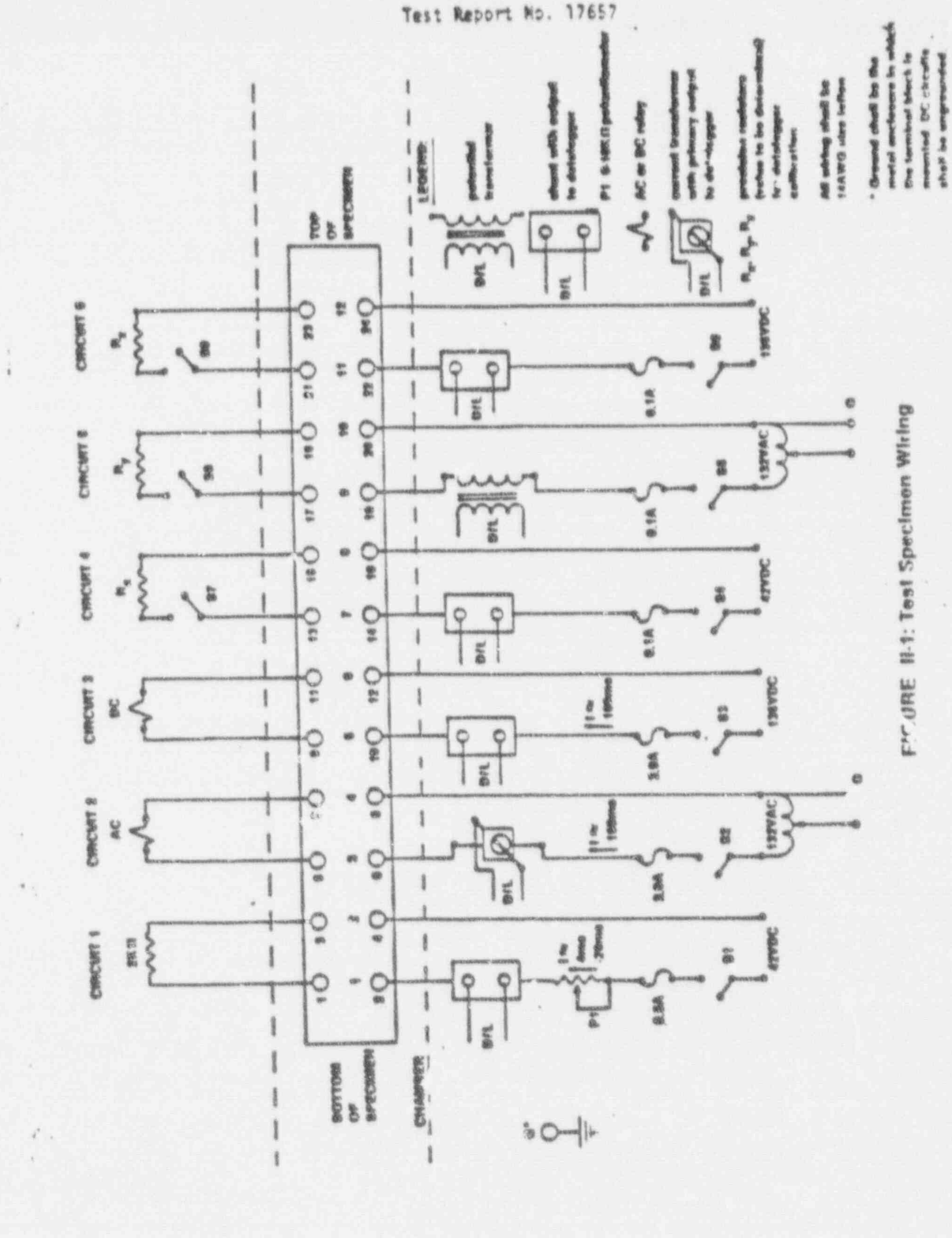


FIGURE II-1: Test Specimen Wiring

outage, the fuses connected to the terminal blocks all opened. In the test, 132 Vac circuits used 12 A fuses, 264 Vac circuits used 18 A fuses, and 528 Vac circuits used 24 A fuses. At other times, the 264 Vac and 528 Vac circuits had fuses open. The conclusion from the tests was that the blocks were not suitable for use in 528 Vac circuits when exposed to the conditions of the test. The opening of the fuses after the power outage was attributed to a test anomaly. However, in some plant applications, the same type of sudden powering may occur, raising the question of whether similar high transient leakage currents could occur in plant applications. The results from the Sandia tests showed the same kind of behavior when voltage was suddenly applied.

Figure 30 gives an indication of the variation of terminal block IR with voltage and temperature noted in Sandia testing. The applied voltage up to 100 hr was 45 Vdc. Note that the steady state IR is lower at the lower voltage and that the IR decreased substantially when power was suddenly applied even though the temperature had decreased. Figures 56 and 57 give additional data which indicates that for terminal blocks, the IR as a function of voltage is difficult to generalize over the small voltage range tested. A theoretical model developed for steady state conditions suggests that IR is constant up to a certain voltage (depending on specific parameters of the moisture film and terminal block), followed by increased IR at higher voltage as the moisture film dries out. Transient conditions are much more difficult to predict, but the experimental data provides two insights consistent with the steady state model: (1) when voltage is suddenly applied, a moisture film has had time to develop (no Joule heating to evaporate it) and the initial leakage current is high, followed by a reduction in leakage current over time as the leakage current heats and evaporates the film, and (2) when steam is first introduced into the environment, whether the block is energized or not, condensation occurs on the block fairly rapidly since the block is still at normal ambient temperature (see discussion of condensation under saturated vs. superheated steam). One final thing to note is that, based on the above discussion, superheated steam testing of terminal blocks is generally not adequate to simulate conditions which might actually be saturated.

Discussion of Limitorque Testing of Terminal Blocks

A Limitorque test (number B0119) was run to determine the suitability of various terminal blocks, including Marathon 1600 series, for use in motor power circuits inside motor operators. The test acceptance criteria was that the IR of unpowered blocks must remain higher than the IR of two powered blocks connected in series which were functionally verified to be capable of operating a motor. The philosophy of this test strategy has been questioned as well as the conclusion of

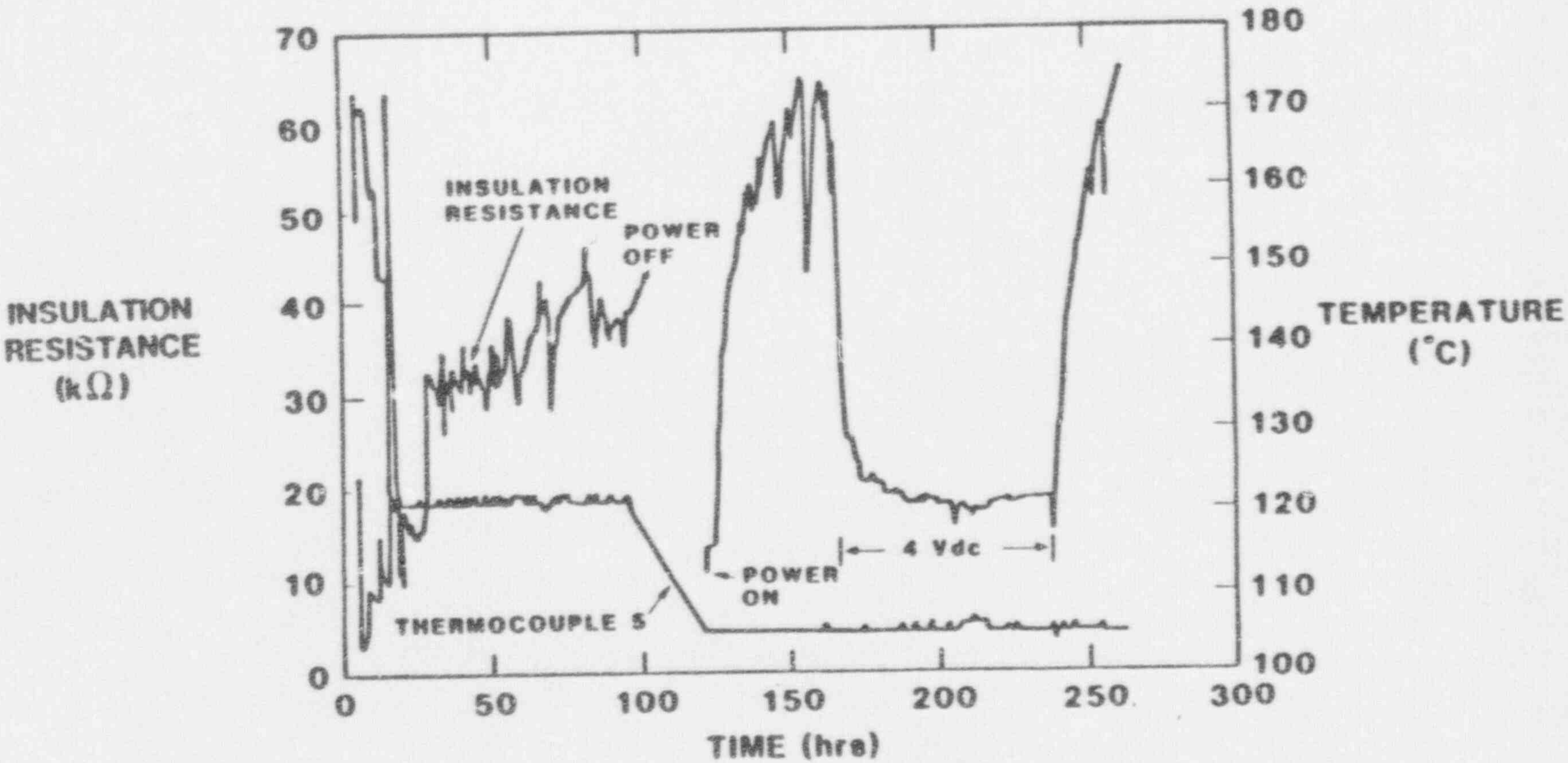


Figure 30

Insulation Resistance for Terminal Block 1 From the Second 172°C Plateau to End of Test. Temperature trace is for thermocouple 5.

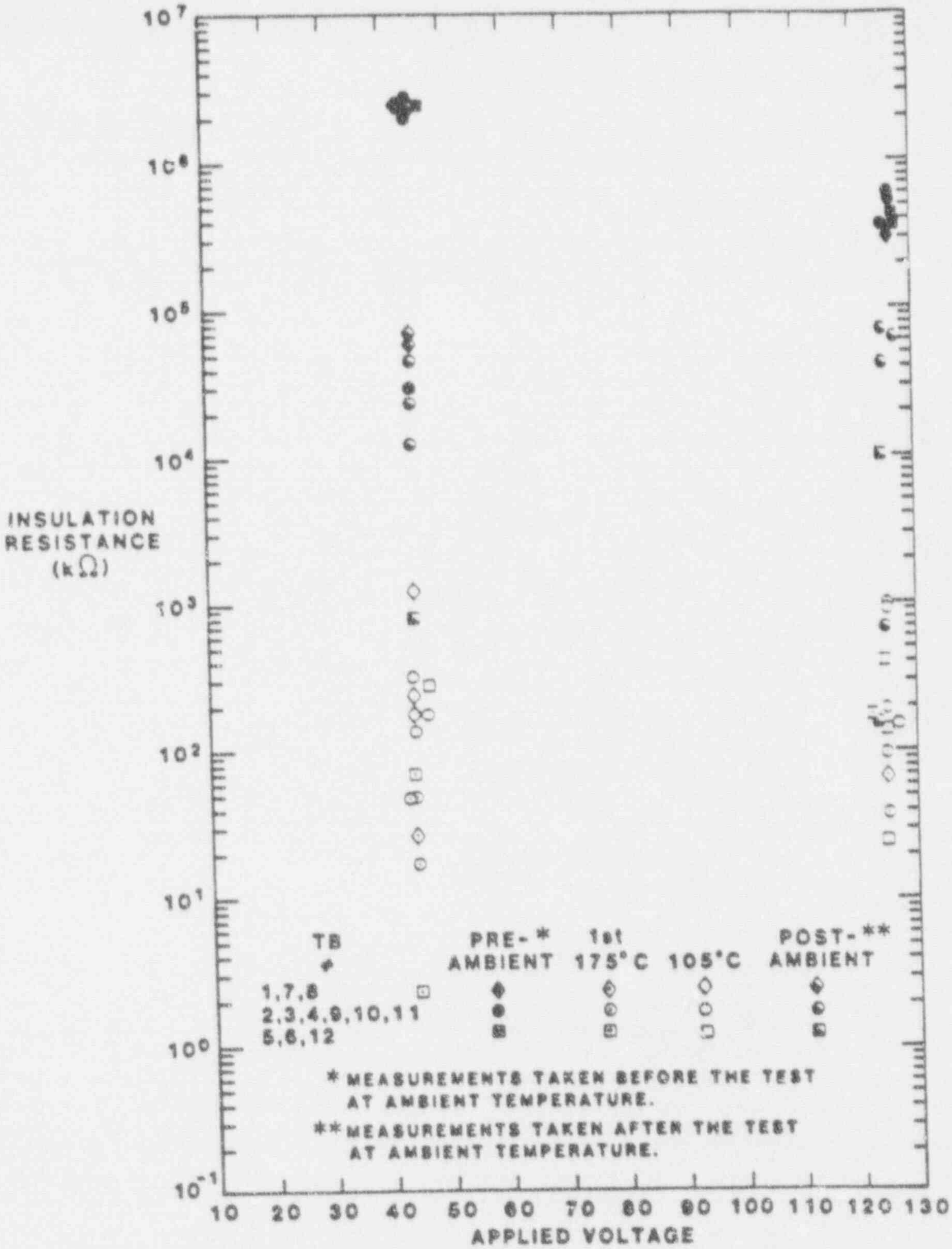


Figure 56

Insulation Resistance A for Pre-ambient, 175°C, 105°C, and Post-ambient Temperature Periods as a Function of Applied Voltage

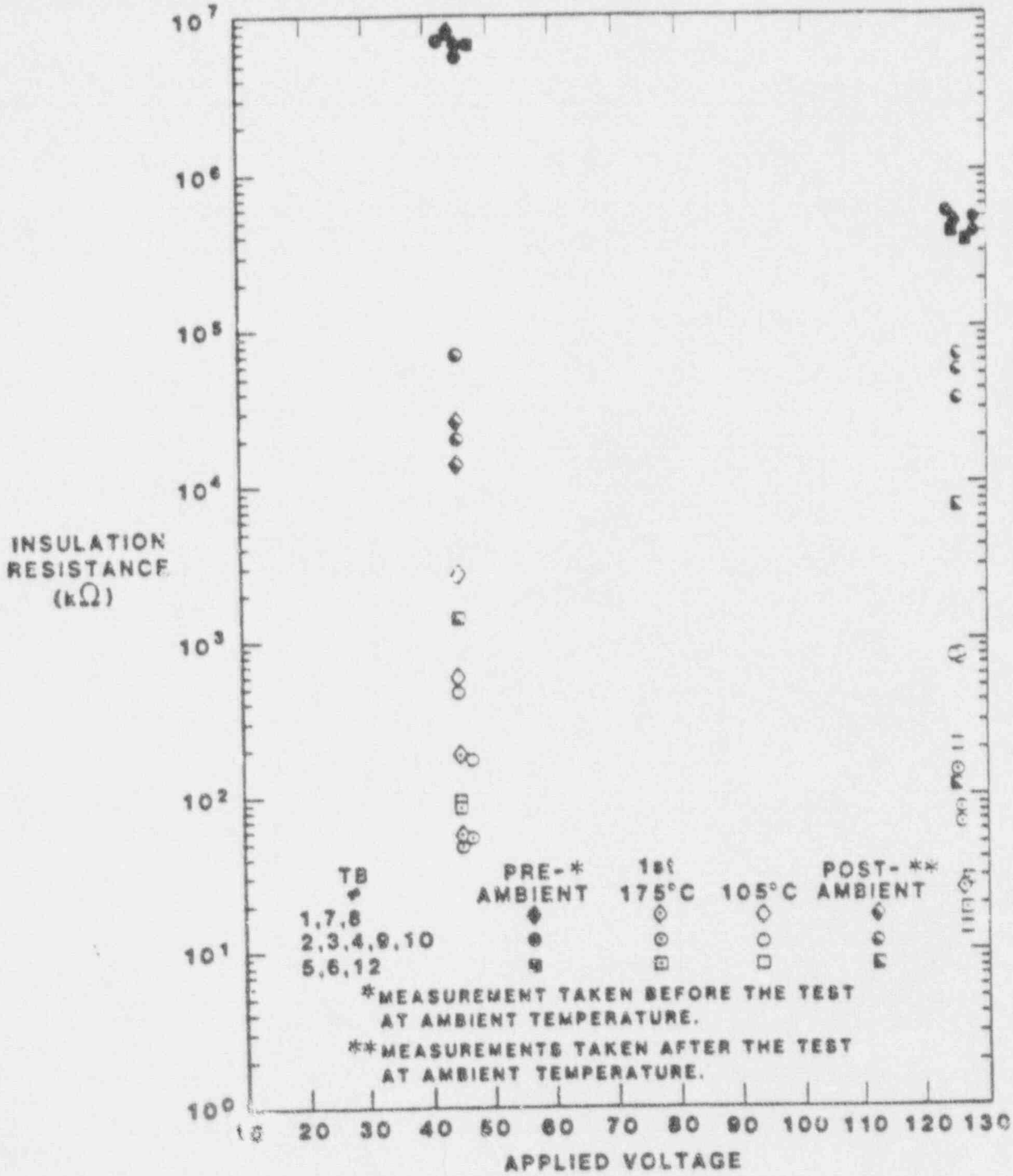


Figure 57

Insulation Resistance B for Pre-ambient, 175°C, 105°C, and Post-ambient Temperature Periods as a Function of Applied Voltage qualification from this test. Let's examine some positive and negative factors in this test:

Positive:

--Considering the discussion above, the unpowered terminal blocks may represent a worst case condition (i.e. maximum likelihood of film formation) with the IR measurements reading more typical of what might be expected in a plant before the motor operator is powered.

--Many tests of terminal blocks at lower voltages indicate that terminal block IR remains sufficiently high for power circuit applications.

--Power circuits are very insensitive to reduced IR of interconnecting devices.

--The test had two terminal blocks in series in the circuit powering the motor, essentially doubling the possible leakage currents.

--Terminal block measurements performed at low voltages may be more conservative than those performed at high voltages under steady state conditions since the higher voltage will drive the conducting film from the block.

Negative:

--The terminal blocks were not all powered during the test except during periodic IR measurements at fairly low voltages.

--The low voltage IR measurements give little direct indication of the terminal block performance at 480 Vac.

--The test strategy of using only IRs as an acceptance criterion is technically weak.

--The Wyle test of Marathon 1600 terminal blocks concluded that they should not be used in 480 Vac applications.

Discussion Notes:

There are numerous additional blocks in use in plants with a partial list as follows:

Weidmuller SAK
States ZWM
Marathon 300/1500/1600
GE EB-5/EB-25/CR151
Curtis L
Amerace (Buchanan) NQB/0222/0524
Westinghouse 5224
Kulka -JJ

Most of the list covers a series of blocks with various numbers of terminals.

Testing by Sandia is reported primarily in NUREG/CR-3418 (data report) and NUREG/CR-3691 (assessment report). Some of the above statements are derived from insights gained during Sandia terminal block testing.

Probably the most significant issue for terminal blocks is that of functional performance requirements during accident testing. Ideally, terminal blocks and other interconnecting devices should be tested in circuits that are identical in every respect to what is installed in the plant. Some more recent terminal block tests have approached this goal by testing with representative loads on the terminal blocks. However, most testing has only been on the devices with some rated loading and possibly periodic leakage current or IR measurements. As with other interconnecting devices, terminal blocks constitute another parallel resistance in the electrical circuit. Individual component sections will discuss the effects of IR on the circuits.

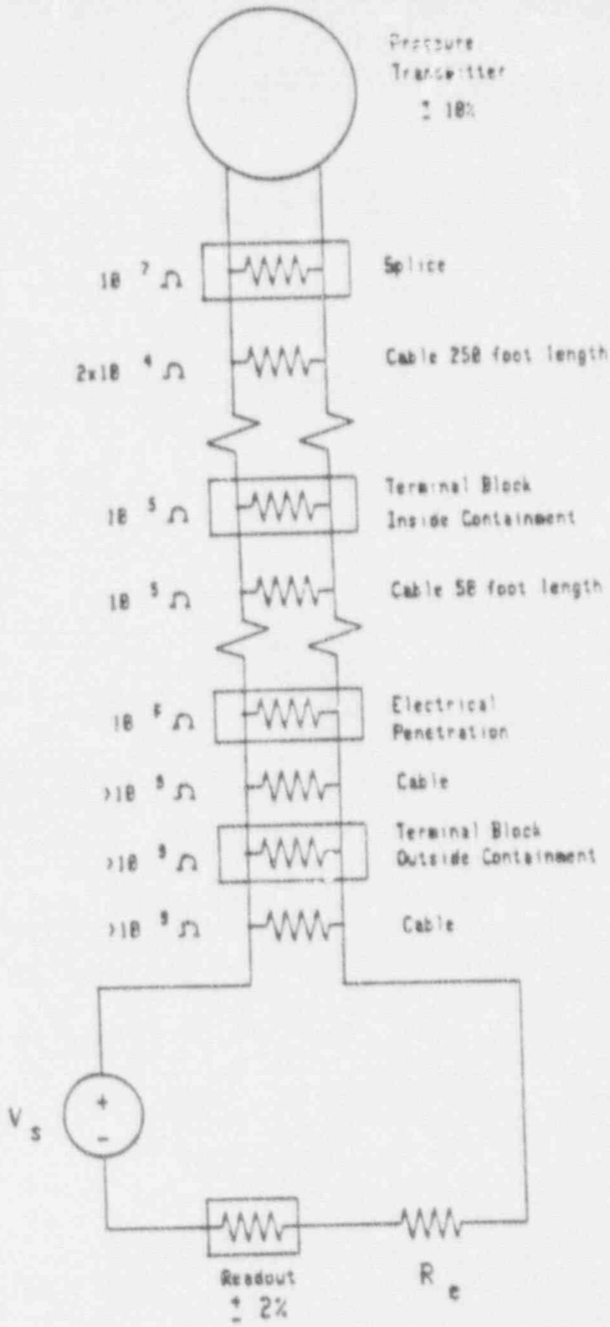
Transmitters

The three major manufacturers of qualified pressure and level transmitters are Rosemount, Barton, and Foxboro. Analysis of functional performance with regard to loop accuracy will be discussed generically; specific issues will be primarily for the Barton transmitters since Sandia has run tests on them.

Figure 1 shows an example of a 4-20 mA pressure transmitter circuit with all interconnecting IRs considered and some possible worst-case values for each during an accident inside containment. In this figure, both a splice and a terminal block are shown inside containment only to show that they are analyzed in exactly the same fashion. The interconnecting devices all contribute to the transmitter inaccuracy in a parallel fashion. Clearly, in this circuit, insulation resistance values of 10^7 or above may be neglected since much lower values are present. The insulation resistance for the cable is assumed to be calculated based on testing of a ten-foot section of cable with an insulation resistance of 5×10^5 during design basis accident testing. The insulation resistance is then scaled down by a factor equal to the ratio of installed cable length to the test cable length inside the test chamber. This is clearly taking a conservative approach to IR scaling since the test chamber penetrations (as well as a small effect from the external lead wires) is included in the measurements. As mentioned earlier, data at Sandia (unpublished) indicates that the scaling approach is reasonable, but that for the longest cables tested, a factor of at least 2 higher IR than that predicted by scaling was typically observed (no such credit was assumed in the present example). A practical approach to scaling might be to choose a reasonable maximum length which could be expected inside a harsh environment, rather than trying to establish the length of each cable.

The equivalent shunt resistance in Fig. 1 is easily calculated as 1.4×10^4 ohms. The analysis proceeds as follows, using the simplified representation of the circuit in Figure 8-1 (showing only one IR, that of a terminal block representing the parallel combination of all other IRs):

A pressure transmitter typically operates with 4-20 mA of current in the instrument loop. At zero pressure, or the low end of the calibrated span, 4 mA is allowed to flow in the circuit, at full pressure 20 mA is allowed to flow. The key word here is "allowed." A transmitter essentially functions as a variable resistor in the circuit, limiting the amount of current flowing in its branch of the circuit to a value proportional to the input pressure; it is not a current source. This characterization is extremely simplified, but it captures the essence of circuit behavior and permits terminal block effects to be analyzed. Figure 8-1 shows how a transmitter might typically be connected in an actual plant application.



Notes:

1. Pressure Transmitter compensates for for errors in V_s.
2. Cable shielding not shown.
3. All errors for accident conditions.
4. Assumes insulation resistance of $5\times10^{8}\ \Omega$ for a 10 foot cable section.
5. Effect of transmitter pigtail is included in transmitter accuracy.

Figure 1 Pressure Transmitter Circuit Showing Interconnections

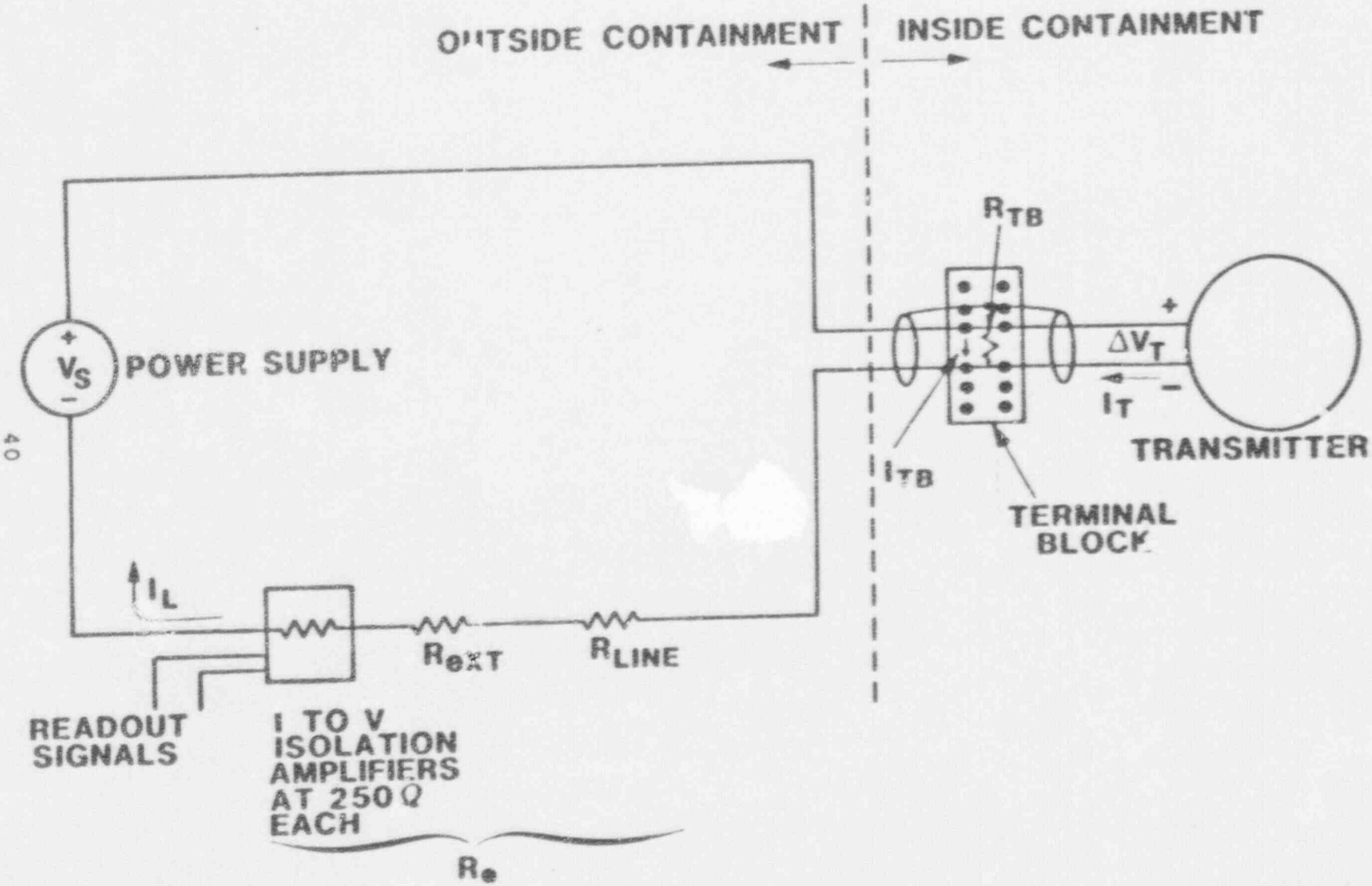


Figure 8-1: Simplified Schematic of a Typical Transmitter Circuit in a Nuclear Power Plant

The transmitter will operate correctly as long as the voltage remains in a specified range. For example, a typical transmitter will operate to specification as long as the voltage across the transmitter terminals remains between 15 and 50 Vdc. The loop resistance external to the transmitter (from the current-to-voltage amplifier., the cable, and the other external resistances) also may vary over a specified range depending on the voltage supplied to the transmitter. For a typical transmitter, if the power supply voltage is 45 Vdc, the external loop resistance may vary between 250 and 1,500 ohms. Note from Figure 8-1 that the potential across the transmitter, ΔV_T, is essentially the potential across the terminal block and therefore would be the driving potential for any terminal block leakage current. ΔV_T can be expressed in terms of the normally constant power supply voltage, V_s, and the voltage drop, ΔV_e, across the external loop resistance, R_e:

$$\Delta V_T = V_s - \Delta V_e$$

$$\Delta V_T = V_s - R_e I_L \qquad \text{Eq. 8-1}$$

where I_L is the total loop current. The leakage current, I_{TB}, across the terminal block is:

$$I_{TB} = \frac{\Delta V_T}{R_{TB}}$$

where R_{TB} is the insulation resistance of the terminal block. The total loop current, which will be observed in the control room as the transmitter signal, will be the sum of the transmitter output current, I_T, and the terminal block leakage current:

$$I_L = I_{TB} + I_T \qquad \text{Eq. 8-2}$$

Under normal conditions, I_{TB} will be zero or negligibly small compared to I_T. However, under accident conditions, I_{TB} can become a sizable fraction of I_T, and therefore, becomes a sizable portion of the total loop current sensed by control room instrumentation. The error, e, in the signal will simply be the ratio of the terminal block leakage current to the transmitter signal current. That is:

$$e = \frac{I_L - I_T}{I_T} = \frac{I_{TB}}{I_T} \qquad \text{Eq. 8-3}$$

Using the above equations, we can express e in terms of V_s, R_e, R_{TB}, and I_T:

$$e = \frac{V_s - R_e I_T}{I_T\left(R_{TB} + R_e\right)} \qquad \text{Eq. 8-4}$$

This analysis gives error in terms of percent of reading. Typically, plants use percent of full scale when defining accuracy. To get error as a percent of full scale, simply substitute the full scale transmitter current for I_T in the denominator of Eq. 8-3 and 8-4. Some plants might use a simpler, more conservative approach. Since $R_{TB} >> R_e$, R_e may be neglected; similarly, $R_e I_T$ in Eq. 8-4 may be neglected. Both of these result in more conservative (larger) errors. Using equation 8-4 modified only to give error as a percent of full scale and using a supply voltage of 50 Vdc, an equivalent external resistance of 1 kΩ, and a transmitter current of 4 mA (worst case) gives an error of 15.3% of full scale. (If the more conservative simplifications were used, the error would be 17.9%). The only remaining problem is that of calculating the total loop accuracy, which may be accomplished by several different methods. The most obvious and most conservative approach would be to simply add the errors giving $\pm(10+2+15.3) = \pm 27.3\%$ total error. A second method would be to use the square root of the sum of the squares of the individual errors giving $\pm(100+4+234)^{0.5} = \pm 18.4\%$ total error. The disadvantage of this latter method is that it assumes that each error is normally distributed about the 0% error point; in actuality, the leakage current contribution to the error can only be in the positive direction. This example is not based on any specific plant or any particular qualification test results--it serves merely as a demonstration of how the error calculations might be done. A 4-20 mA pressure transmitter circuit was chosen for this example since it is often a limiting circuit in actual plants if coaxial and triaxial cable is treated separately.

Every equipment qualification circuit in the plant should be evaluated as indicated above or in some alternative fashion. From a practical standpoint, a somewhat generic approach is desirable. One such approach used by a utility was to establish generic acceptance criteria for each individual interconnecting device. The approach might choose a value of 0.1 megohm per device (after insulation resistance has been scaled for differences between tested length and installed length), coupled with a generic reference showing that the resulting error is acceptable in plant circuits with the maximum expected number of interconnecting devices. If any device exhibits an insulation resistance less than the analyzed value, a circuit specific analysis would be performed to determine acceptability of the device.

Sandia has performed testing of Barton transmitters as reported in NUREG/CR-3863. The salient points of the research may be summarized as follows:

--The Barton transmitter electronics are extremely radiation hard, surviving a 400 Mrad total dose exposure with maximum errors around 5%.

--The major stress affecting transmitter operation is that of thermally induced errors resulting from potentiometer degradation. Barton has recommended installation of electrical isolation washers between the potentiometer and housing, which appears to reduce thermal effects by treating the symptoms of the problem.

--A potentiometer failure (open circuit) was also observed during testing. Analysis of the potentiometer indicated that corrosion was apparently responsible for the failure with the potentiometer lubricant a primary contributor to the corrosive environment.

--Time at temperature behavior indicated that thermal aging exposure may actually improve the transmitter's performance when subjected to an accident environment.

An additional concern has been identified with the gland seals used in the Barton transmitters, with several failures noted during testing by Westinghouse. The failures are manifested as moisture and corrosion products getting into the gland seal and causing corrosion and eventual opening of the lead wires. Barton has performed additional testing and analysis to justify that the anomalies were test artifacts, but some doubt still remains that the testing is conclusive for lengths of cable typically installed in plants. The analysis has been considered accepted unless additional adverse information is obtained.

One problem found for Rosemount transmitters is the failure of utilities to install plugs in the alternate cable entrance. Two cables entrances may be provided at opposite ends of the transmitter and only one is used. The other one usually has a plastic cap installed from the factory. The plastic cap must be removed and replaced with an appropriate plug.

Limit Switches

The only vendor currently known to produce qualified limit switches for inside containment, harsh environment usage is Namco. The problems with limit switches have been primarily the lack of qualified conduit seals installed on the devices. Some older models of limit switches no longer produced have had isolated instances of other problems and different models of limit switches have had some operational problems not related to qualification.

The need for qualified conduit seals arises from the method of testing the limit switches: the conduit entrance to the limit switch had sealed conduit attached and the conduit penetrated the test chamber such that the cable and switch interior were not exposed to the steam environment.

The primary effect of potential leakage currents on the operation of a limit switch would be related to false indications. The following is an analysis of the potential effects of leakage currents on a solenoid valve circuit using limit switches.

Terminal blocks are commonly installed in 120 Vac and 125 Vdc control circuits for solenoid valves. Figure 8-12 is a simplified schematic showing one possible solenoid valve circuit. Before addressing the effects of terminal blocks, it is important to understand the normal

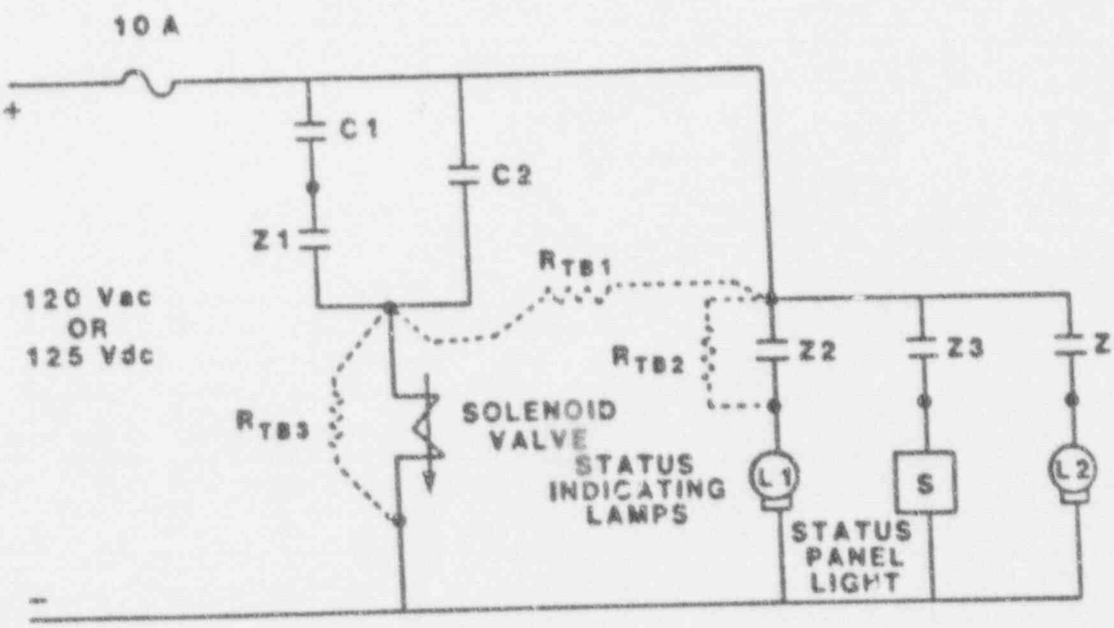


Figure 8-12: Simplified Circuit Schematic for One Possible Solenoid Valve Circuit

operation of this circuit. To begin, assume that the valve is normally open and that when energized, it closes. The desired position for operation is open.

The contacts C1 and C2 are control switches in the control room. These switches can be any one of a number of types, but a common type might be three position momentary contact switches. That is, there is a neutral position which is the rest position for the switch, and there are open and close positions which must be held by an operator in order for the switch to make contact in that position. Thus, when an operator moves the lever to open and releases it, the switches return to the neutral position. Assume that both C1 and C2 are operated by the same lever. Z1, Z2, Z3 and Z4 are two position limit switches located on the valve itself. L1 and L2 are indicator lamps in the control room and indicate that the valve is not closed and not open, respectively.* S is a status panel light which lights when the valve is in the normally desired position. Tables 8-2 and 8-3 are the contact development tables for this circuit. An "x" means that contact is made in that switch position.

Table 8-2

Contact Development Table For Control Switches C1 and C2

	---Switch and Valve Position---		
	Open	Neutral	Close
C1	-	x	x
C2	-	-	x

x = contact made
- = contact not made

---

* The terms "not open" and "not closed" are used rather than "closed" and "open" because that is the true meaning of the lamp. The "not open" lamp lights when the valve leaves the open position and is thus lit both while the valve is closing and when it is closed. Similarly the "not closed" lamp lights when the valve leaves the closed position and is thus lit both while the valve is opening and when it is open. If both lamps are lit simultaneously, then "not open" and "not closed" are both true which means that the valve is changing state. If only one lamp is lit, then it means that the valve is either open ("not closed") or closed ("not open").

Table 8-3

Contact Development Table for Limit Switches Z1, Z2, Z3, and Z4

	Valve Position		
	Open	Intermediate	Close
Z1	-	-	x
Z2	x	x	-
Z3	x	-	-
Z4	-	x	x

x = contact made
\- = contact not made

If the valve is open, we see from Tables 8-2 and 8-3 that C1, C2, Z1, and Z4 are open. Only Z2 and Z3 are closed which means L1 and S are lit and the indication is that the valve is open (see footnote on "not open" and "not closed"). If the operator now wants to close the valve, he moves the lever for C1 and C2 to the "close" position. Both C1 and C2 make contact and, because Z1 is still open, power is applied to the valve via C2. The valve begins to close; Z3 trips open extinguishing S and Z4 trips closed lighting L2. Both L1 and L2 are now lit, and hence we know the valve is changing position. If the operator releases the lever before the valve is fully closed it will return to the full open (nonenergized) position since Z1 is not yet closed and C2 is open when in the neutral position. When the valve reaches the fully closed position, Z1 and Z2 change state. Z1 closes so that when the operator releases the switch lever, power to the valve will be applied through C1 and Z1; Z2 opens turning L1 off. The sequence happens in reverse when opening a closed valve. The operator moves the switch lever to open, thus opening C1; C2 was already open. Power to the valve is lost and it begins to open. As it does, Z1 and Z2 change state. Z1 opens to ensure that power will not be reapplied when C1 is released to the neutral position. Z2 closes, lighting L1. When the valve reaches fully open, Z3 and Z4 change state. Z3 closes, lighting S, and Z4 opens turning L2 off

The dots in Figure 8-12 indicate circuit nodes which are physical junctions to field wiring near the valve. These may very likely be adjacent terminals on a terminal block. Three possible terminal block leakage paths have been indicated on Figure 8-12 by dotted resistors. Each may have a detrimental effect on the operation of the solenoid circuit. First, consider R_{TB1}, a leakage path between the always powered node of Z2, Z3, and Z4, and the solenoid valve. This leakage path bypasses the valve control switches C1, C2, and Z1. The effect of this leakage current could be the inadvertent energizing of the valve when a steam environment quickly envelopes the terminal block. If R_{TB1} is small enough, a leakage current sufficient to power the valve may occur. If the valve in question is a 17.4 watt, dc service valve, then the steady state resistance of the valve is:

$$R_V = \frac{(125\ V)^2}{17.4\ W} = 900\ \Omega$$

In actuality, because of the finite value of R_{TB1}, the entire power supply potential will not be dropped across the solenoid valve. The minimum voltage to actuate the valve is approximately 90 Vdc [49] and hence the current necessary for this condition is:

$$I_V = \frac{90\ V}{900\ \Omega} = 0.1\ A$$

If at least 90 volts must drop across the solenoid valve, then a maximum of 35 volts can drop across R_{TB1}. Using the 0.1 A current requirement to operate the valve, we see that:

$$R_{TB1} = \frac{35\ V}{0.1\ A} = 350\ \Omega$$

Thus, a transient terminal block insulation resistance of 350 ohms would cause the valve to close when it was intended to be open. Industry qualification tests experience leakage currents sufficiently large to indicate that such low IR values are possible. Further, low values of IR would be most likely to occur under transient conditions (see Figures 4-6 and 8-3). The question here is whether or not such low values of IR would prevail for a period sufficiently long to complete the closing of the valve. Sandia test results indicate that the answer is probably yes, because solenoid actuation is fairly rapid and the low values of terminal block IR prevailed for seconds to minutes after their onset.

Next consider the leakage path designated by R_{TB2}. This path is a leakage path by limit switch Z2 and the net result could be a false lighting of indicating lamp L1. Analogous paths, not shown in Figure 8-12, would erroneously light lamps L2 or S. The current and voltage required to light L1 will undoubtedly vary from design to design, but two cases might be considered as examples. In the first case, the lamp is in a series connection as shown in Figure 8-12. A typical 125 Vdc lamp for such an application might require a minimum of 110 Vdc to operate.[50] The lamp itself might typically have a resistance of 2000 ohms and hence the current necessary would be:

$$I_{Lamp} = \frac{110\ V}{2000\ \Omega} = 0.055\ A$$

Thus, the terminal block insulation resistance would have to be:

$$R_{TB2} = \frac{15\ V}{0.055\ A} = 273\ \Omega$$

Again, this value of IR is not unreasonable for transient conditions though sustained values at this low level are unlikely.

The second lamp configuration would replace the actual lamps with a relay which would turn separately powered lamps on or off. Thus L1, L2, and S would be the pick-up coils for these relays. Such relays might typically have a pick-up voltage of 75 percent of the rated voltage and a coil resistance of 13000 ohms. The required current therefore would be:

$$I_{relay} = \frac{(0.75)(125\ V)}{13000\ \Omega} = 0.0072\ A$$

The voltage drop across the terminal block could be at most 25% of 125 Vdc or 31 Vdc and hence:

$$R_{TB2} = \frac{31\ V}{0.0072\ A} = 4300\ \Omega$$

Thus, a much larger terminal block IR would permit false operation of the indicating or status lamps if they were switched on and off by a relay. Any value of R_{TB2} less than 4300 ohms would cause the lamps to falsely illuminate for the assumed type of relay.

The final fault shown in Figure 8-12 is R_{TB3}. This path leaks by the valve itself and would cause a problem only if the leakage current became large enough to make the circuit fuse fail. For the worst case with a 17.4 watt dc valve energized and all three lamps illuminated, the current in the circuit would be:

$$I_{max} = \frac{17.4\ W}{125\ V} + 3 * \frac{125\ V}{2000\ \Omega} = 0.327\ A$$

If the circuit were fused at 10 A, then 9.673 A would have to leak around the valve to cause the fuse to fail. With the valve remaining energized at 125 V, fuse failure would occur at a terminal block IR of:

$$R_{TB3} = \frac{125\ V}{9.673\ A} = 13\ \Omega$$

This value is essentially a dead short; however, if the circuit were fused at 1 A, fuse failure would occur at a terminal block IR of 186 ohms. These low IR values are not impossible to achieve, but for any sustained period seem improbable. Momentary high leakage currents may cause the fuse to open. At these high leakage current levels, one must also be concerned with the power being dissipated by the terminal block and the effect such power dissipation may have on permanently degrading the block's surface.

In summary, the above discussion indicates that terminal blocks may interfere with the proper operation of a solenoid valve circuit when the terminal block's insulation resistance decreases to about the 4 kohm level. At this value of terminal block IR, indicating lamps may falsely light depending on how they are wired into the circuit. At a few hundred ohms of insulation resistance, the valve may falsely energize and at a few ohms of insulation resistance the leakage current may be large enough to fail circuit fuses. Being slightly conservative, we may conclude that at IR values above 5 kohms, terminal blocks probably do not affect the operation of solenoid valve circuits.

Resistance Temperature Detectors (RTD)

RTDs are basically simple devices whose resistance varies as a function of the temperature the RTD is exposed to. The most significant concern identified for RTDs is failure to monitor RTD accuracy during exposure to steam environments. Some technical basis does exist to support that calibration before and after accident testing verifies RTD operability and that IR effects can be used to determine accuracy during accident conditions. This approach has not been considered totally acceptable by the staff. The required accuracy of the RTD is one important consideration in determining the acceptability of this approach as well as other information which may be available at a given utility. The staff position remains that evaluation should be on a case by case basis with particular attention paid to acceptance criteria. Sandia testing of RTDs is reported in NUREG/CR-3597 and did monitor functional performance during accident testing. The one model tested that was qualified by the manufacturer (Rosemount) performed well. The others, not qualified by the manufacturers, failed in some cases, primarily due to moisture intrusion in the RTD head.

A second RTD concern is consideration of self-heating effects on RTD aging. Some RTDs are used to monitor hot fluid temperatures and may be subject to significant process heating. A memo examined at one test lab indicated that the self-heating effect at one plant could increase the service temperature from 140°F to 223°F when monitoring 650°F reactor coolant. Actual Sandia test data has indicated that the heat rise may not be quite so bad, but may be on the order of 50°F or less, depending on plant specific installations.

The following is an analysis of the potential effects of leakage currents on an RTD circuit. Although IR effects on a 4-20 mA circuits typically produce more error than for RTDs, RTDs may have more stringent accuracy requirements. The analysis determines fractional error, with the extension to percent of full scale left as an exercise.

An RTD circuit typically operates at 4 Vdc or less with currents in the range of 1 mA or less. The resistance in a typical RTD might vary from 200 ohms to 500 ohms over the full temperature range of the RTD. Figure 8-5 shows in a very simplified block form how an RTD circuit will look using a terminal block to connect the RTD to the remainder of the circuit. The IR of the terminal block is a parallel connection with the RTD resistance. Hence, the bridge or constant current circuit used to sense the resistance of the RTD is actually sensing the effective resistance, R_{eff}, of this parallel combination. R_{eff} is:

$$R_{eff} = \frac{R_{TB} R_{RTD}}{R_{TB} + R_{RTD}}$$

and the fractional error e is:

$$e = \frac{R_{RTD} - R_{eff}}{R_{RTD}} = 1 - \frac{R_{TB}}{R_{TB} + R_{RTD}} \qquad \text{Eq. 8-5}$$

For a typical 200-ohm RTD which varies in resistance from 200 to 480 ohms over its temperature range, a terminal block resistance of 10,000 ohms introduces an error in measured resistance of 2.0% at the low end of the calibration and an error of 4.6% at the high end. Figure 8-6 shows the two bounding curves of percent error in measured resistance for a commonly used 200-ohm RTD as a function of terminal block insulation resistance. For an RCS temperature monitor calibrated from 93°C (200°F) to 399°C (750°F) the 2.0% and 4.6% resistance errors translate to a 4°C (7°F) error at the low end and a 24°C (43°F) error at the high end. Since the parallel connection will make the measured resistance less than the actual RTD resistance, the indicated temperature will always be lower than the actual temperature.

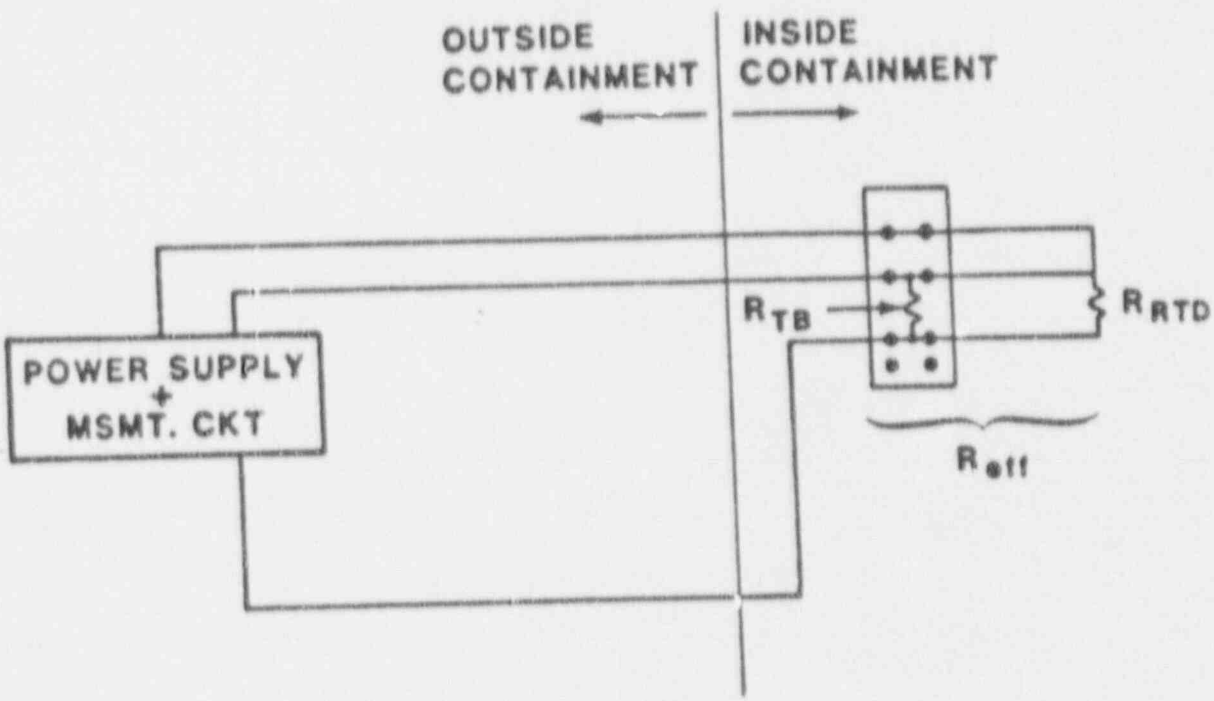


Figure 8-5: Simplified Block Diagram of a 3-Wire RTD Circuit Showing Parallel Connection Between Terminal Block Insulation Resistance and the Resistance of the RTD Sensing Element

High Range Radiation Monitors (HRRM)

The primary deficiency noted with radiation monitors has been the failure to meet performance requirements set forth by RG 1.97. The General Atomics (GA) HRRM has been tested and analyzed at Sandia and the report (NUREG/CR-4728) will be issued shortly. The major conclusions of the report are as follows:

--The HRRM accurately monitors high dose rates during accident conditions.

--The HRRM does not always accurately monitor low dose rates in accident environments.

--One failure mechanism for the above is due to insulation resistances of interconnecting devices failing to meet the GA specifications of $10^9\,\Omega$ each for the electrical penetration and the other interconnections considered together (for a net parallel IR of $5\times10^8\,\Omega$ minimum). The industry had not previously recognized this problem.

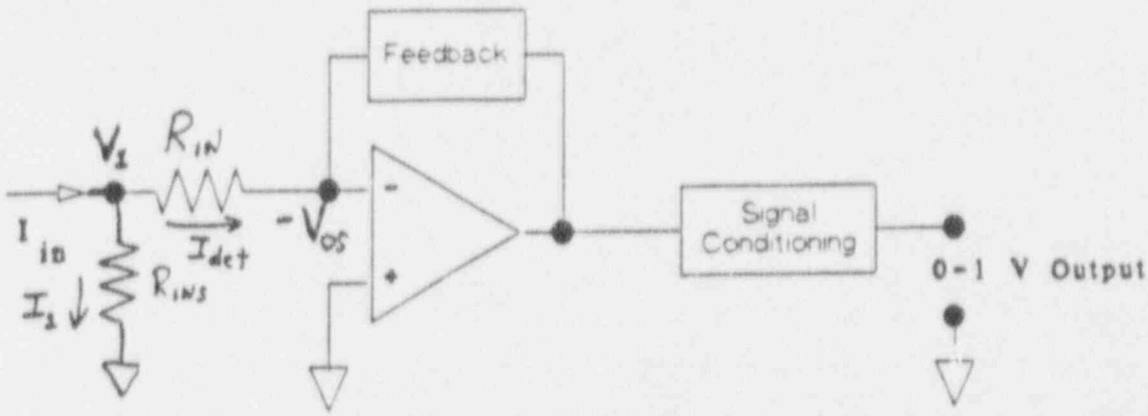
--A second failure mode at low dose rates involves an unknown mechanism, postulated to possibly be galvanic action.

--The operate light on the GA monitor will likely go out early during accident conditions, indicating a fault with the monitor; resetting the monitor will allow it to operate properly if the dose rate has increased sufficiently. However, without knowing the details of the detector operation, operators could potentially be misled by the failure indication.

--The effects of interconnection IR can be modelled by a fairly simple technique, but the other effect is still somewhat unknown. The following gives an analysis of IR effects on the GA HRRM:

We believe that knowledge of the offset voltage characteristics of the readout module's input operational amplifier is critical to assessing the loss of accuracy of the readout module due to insulation resistance effects. To illustrate the point, an operational amplifier circuit is shown in Figure 13. In this circuit, under ideal conditions, all of the input current is diverted around the input amplifier and through select feedback elements. Under these conditions, the negative terminal of the input amplifier acts as a "virtual" ground, i.e. the voltage across the amplifier inputs, V_1, is very nearly at ground potential. The output voltage of the amplifier must be $V_{out} = -A*V_1$, where A is the open loop amplifier gain. (The amplifier gain could vary over a wide range, but a typical value might be around 2×10^5.) The actual voltage V_1 is "adjusted" by the feedback elements such that the desired closed loop properties of the output voltage are achieved. As an example of the voltage at V_1, consider the above open loop amplifier gain and an output voltage of 5.0 V. The resulting voltage V_1 is easily calculated as 0.025 mV (indeed a "virtual" ground). Any input offset voltage is automatically compensated for by the feedback elements since

Figure 13. Block Diagram of Operational Amplifier Circuit.



the input current is completely controlling the feedback characteristics. This compensation is manifested as the above calculated voltage "floating" on the input offset voltage. In the above example, if the input offset voltage were +1.5 mV, the actual voltage V_1 would be -1.5 mV + 0.025 mV = -1.5 mV, or essentially just the offset voltage (negative offset voltage since V_1 is located at the negative amplifier input). In fact, regardless of the amplifier output over a wide range, V_1 remains at approximately the negative of the offset voltage as long as the amplifier open loop gain is high.

Next, consider the effect of finite insulation resistance and nonzero input offset volta on the circuit of Figure 13. Finite IR will exist from cab , connectors, penetrations, or other interconnecting devices. The voltage V_1 is nearly at ground potential (-1.5 mV for the case described above). The following analysis demonstrates how errors due to IR effects may be predicted analytically if the input offset voltage is known. As discussed above, V_1 is essentially constant over much of the range of detector currents if the amplifier gain is high. Thus the input offset voltage can be easily measured as the voltage V_1 with a small input current. For a given detector, the input offset voltage might be 1.5 mV (V_1 = -1.5 mV). Referring to Figure 13 and summing currents at node 1 gives:

$$I_1 + I_{det} = I_{in} \quad (1)$$

With $I_1 = V_1 / R_{ins}$, (1) becomes:

$$\frac{V_1}{R_{ins}} + I_{det} = I_{in} \quad (2)$$

With $I_{in} = (V_1 + V_{os}) / R_{in}$, where V_{os} is the amplifier input offset voltage, (2) becomes:

$$\frac{-V_1}{R_{ins}} + I_{det} = \frac{V_1 + V_{os}}{R_{in}} \qquad (3)$$

Solving (3) for V_1 gives:

$$V_1 = \left(\frac{R_{in} R_{ins}}{R_{in} + R_{ins}} \right) \left(I_{det} - \frac{V_{os}}{R_{in}} \right) \qquad (4)$$

Finally, using (4) in (2) and rearranging gives:

$$I_{det} = I_{in} \left(\frac{R_{ins}}{R_{in} + R_{ins}} \right) - \frac{V_{os}}{R_{in} + R_{ins}} \qquad (5)$$

Equation (5) gives an expression for the current actually measured by the readout module for a given offset voltage and a given insulation resistance between the center conductor and shield of the coaxial cable.

Equation (5) works quite well for IR effects as has been verified over a range of values based on experimental Sandia data. It should be emphasized that this assessment required the knowledge of the input offset voltage of the readout module input operational amplifier. The offset voltage is a random parameter and might typically be within the range of -3.0 mV to +3.0 mV. Consequently, without knowing the input offset voltage for a given device, neither the magnitude nor even the direction of the error is predictable. However, given the manufacturer's specifications for the input amplifier, bounds can be put on the IR-induced error as a function of the detector current and the interconnection insulation resistance by using equation (5).

Equation (5) can also be used to give a qualitative assessment of the readout module's behavior by considering the two terms of the equation separately. The first term represents the loss of signal generated by leakage of detector current to ground; the factor in parenthesis is always a positive quantity less than 1.0. The second term represents the contribution of the amplifier input offset voltage to the input current and may be either positive or negative. If the input offset voltage is positive (as in our case), it causes additional current to flow into the readout input because V_1 is approximately the negative of the offset voltage and is thus below ground potential, causing current to be drawn from ground. A reverse argument holds for a negative offset voltage, but the result is current drawn from the readout module. In this second case, at low detector currents, the readout module will tend toward going off-scale on the low end (due to both terms). At low detector currents, the second term of equation (5) tends to control readout behavior, while at high detector currents, the first term tends to control the behavior. For any given interconnection insulation resistance, the undesirable effects modelled by equation (5) are much more pronounced for the low detector currents (mainly the second term of equation (5)).

It should be emphasized that the effects modelled by equation (5) are only IR induced. Another effect, which was not even positively identified, tended to dominate detector behavior at low detector currents. Consequently, analysis using calculations such as equation (5) may be of somewhat limited value.

The other major detector used by the industry (Victoreen) has not been tested or evaluated as the GA has. Some of the above concerns may also apply to the Victoreen. The Victoreen HRRM includes installation requirements that the cable used be installed in sealed conduit. This requirement came about from the numerous difficulties and anomalies that were encountered in testing of the detector. One piece of information in the Victoreen qualification indicates that a loop IR of 10^6 Ω is sufficient for detector operation, but no basis is given for this value. (The GA requirement also gives no basis, but the equation developed above can be used to show that the GA criteria is adequate if a reasonable worst-case amplifier offset voltage is assumed.)

Appendix B
Activation Energies

B.1 TABULATION

Activation energies for a number of materials and components are tabulated in this appendix. As in Appendix D, no effort was made to produce an exhaustive tabulation; rather, it is a convenient recording of activation energy data obtained incidentally to preparation of this report. It is essential that the cited data sources be consulted to verify the relevance to the user's application.

B.2 HISTOGRAM

A graphical representation of the distribution of activation energies, for the materials and components included in the tabulation is given by the histogram in Figure B-1.

The values of activation energy range from 0.09 eV for titanium-titanium dioxide, thin-film capacitors to 3.29 eV for Kraft paper. This range was divided into 0.2-eV increments, and the number of materials and components that have an activation energy within a given increment was counted (from the tabulation). These numbers were then used to plot the histogram. The large number of entries for magnet wire contributes substantially to the histogram over a broad range from 0.2 to 1.8 eV, except in the interval between 1.2 and 1.4 eV. Polymers and transistors make a major contribution to the peak between 1.0 and 1.2 eV.

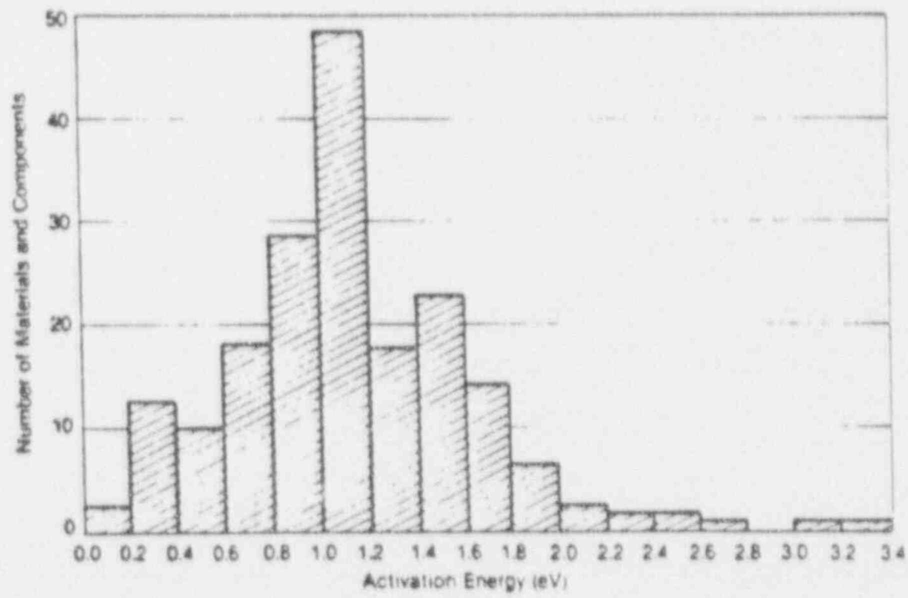


Figure B-1.
Histogram of Activation Energies

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Capacitors, chlorinated diphenyl, 0.5% azobenzene	2.00	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper	0.86	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 0.5% azobenzene	1.50	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 5.0% azobenzene	1.93	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitor, dielectric, tubular paper	2.42	717	10% capacitance increase. See Note 14.
Capacitors, metalized paper	1.32	180	Life defined as time required to regain original value of capacitance after initial increase. See Note 14.
Capacitors, titanium-titanium dioxide, thin-film, @ 25°C-100°C	0.09	466	Formed by anodization. Tests with rate of temperature rise approximately 2½°C/min.
Choseal (Chomeric Inc.) (Silver filled conductive silicone)	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Connectors: Thin gold (25-100μ) electroplated over copper base material			$D = D_o \exp(\varphi/kT)$, where D = chemical interdiffusion coefficient and $D_o \cong 1.5 \times 10^{-5}$ cm²/s.
(250°C - 750°C)	1.02	433	Predominant degradation mechanism is defect diffusion along grain boundaries and dislocation pipes – dependent upon defect density.
(50°C - 250°C)	0.50	433	
Dacron, Parachute material (polyethylene glycol terephthalate, see see Ref. 124)	1.15	765	Determined by thermogravimetric analysis. Heating rate of 2°C per minute
Diallyphthalate, glass filled	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Diodes, Si – general	1.13-2.77	340	
Diodes, Si (–1960)	1.14	340	

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Operational Amplifier 741			
– freak pop.	0.7	517	
– main pop.	1.6	517	
– mixed pop.	0.8	517	
– freak pop.	0.8	517	
– main pop. (½ voltage)	0.9	517	
Paper, manila, under oil	1.66	566	Reduction of tensile strength to 20% of original strength. See Note 14.
Paper, manila, under oil	1.56	566	Reduction of tensile strength to 70% original strength. See Note 14.
Penolic, general purpose, Durez 791	1.36	1026	50% retention of impact strength (Hooker Corp.). See Note 14.
Phenolic, general purpose, Durez 791	1.05	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	0.96	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	1.11	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.16	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.43	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 685	1.27	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic-Kraft laminate	1.47	573	75% retention of flexural strength. See Note 14.
Phenolic-Kraft laminate	1.50	573	50% retention of flexural strength. See Note 14.
Polyester, amide-imide overcoated, helical coil	1.54	943	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Epoxy, Grade 2000	1.24	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Epoxy insulation on magnet wire	0.99	610	See Notes 1 and 11.
Epoxy insulation on magnet wire	0.94	610	See Notes 2 and 11.
Epoxy insulation on magnet wire	0.87	610	See Notes 3 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 4 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 5 and 11.
Epoxy insulation on magnet wire	0.93	610	See Notes 6 and 11.
Epoxy, unvarnished, magnet wire	0.67	832	See Note 14.
Epoxy, phenolic varnished, magnet wire	0.66	832	See Note 14.
Formvar (Bondege), cementable insulation and Andover Corp. epoxy encapsulant	1.09	320	See Note 14.
Formvar, cementable insulation and epoxy encapsulant – solenoid coil	0.70	320	See Note 14.
Formvar insulation on magnet wire	1.61	610	See Notes 1 and 11.
Formvar insulation on magnet wire	0.23	610	See Notes 3 and 11.
Glass, high lead	0.37	97	
Isonel – 175 insulation and Acme 2008 epoxy encapsulant on solenoid coil.	0.68	320	Average coil life. See Notes 12 and 14.
Kraft paper in mineral oil.	1.39	838	50% of tensile strength. See Note 14.
Kynar, MIL-specification wires	1.95	374	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polythermaleze #33 on coils.	0.87	610	See Note 7. Failure criteria was shorted turn, open circuit and/ or 2500 volt hipot failure of coil.
Polystyrene	0.26	890	
Polyurethane insulation on magnet wire.	0.49	610	See Notes 6 and 11.
Polyurethane insulation on magnet wire.	0.29	610	See Notes 4 and 11.
Polyurethane insulation on magnet wire.	0.32	610	See Notes 5 and 11.
Polyurethane insulation on magnet wire.	0.38	610	See Notes 2 and 11.
Polyurethane insulation on magnet wire.	0.28	610	See Notes 3 and 11.
Polyurethane insulation on magnet wire.	0.46	610	See Notes 1 and 11.
Polyvinylacetate	0.16	890	
Polyvinylchloride	0.26	890	
Polyvinyl formal, magnet wire twists, with phenolic alkyd varnish.	0.80	832	See Note 14.
Polyvinyl formal, magnet wire, with phenolic type varnish.	0.82	832	See Note 14.
Polyvinyl formal, with phenolic type varnish, magnet wire.	0.93	832	See Note 14.
Polyvinyl formal, with phenolic type impregnating varnish, magnet wire.	1.04	832	See Note 14.
Polyvinyl formal, unvarnished, magnet wire.	1.01	832	See Note 14.
Polyvinyl formal enamel and oil modified phenolic varnish, magnet wire.	0.98	368	See Note 14.
Polyvinyl formal, un-phenolic type varnish, magnet wire.	0.84	832	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Thermaleze "B" (epoxy polyester film), insulation magnet wire.	1.0	368	See Note 14.
Thermaleze-F insulation and Jones-Dabney epoxy encapsulant.	1.10	320	See Note 14.
Thermalon insulation and 3M 241 epoxy encapsulate on solenoid coil.	0.42	320	Average coil life. See Notes 12 and 14.
Transistors	0.66	123	
Transistor, Ge alloyed, OC 1972 (1964)	1.26	235	
(1966)	1.08	235	
Transistor, Ge alloy LT123 (1958).	1.25	670	
Transistor, bipolar, p-n-p-n	1.65	340	
Transistors, CMOS	1.18	334	Eyring model.
Transistor, diffused-geronium	0.87	340	Step-stress tests without moisture getter. Median life. See Note 14.
Transistor, diffused-germanium	1.24	340	Constant stress tests with moisture getter. Median life. See Note 14.
Transistor, Ge gettered	1.24	340	
Transistor, Ge mesa, AF106 (1969)	1.00	235	
Transistor, Ge mesa, 2N559 (1958)	1.17	671	
(1959)	0.95	671	
(1960)	1.14	671	
Transistor, Ge MADT, 2N501 (1958)	1.07	673	MADT = Micro alloy diffused transistor
Ge MADT, 2N501 (1959)	1.07	674	
Transistor, Ge MAT, 2N393 (1960)	1.0	673	MAT = Micro alloy transistor
Transistor, Ge MAT, 2N393 (1959)	1.00	673	MAT = Micro alloy transistor
Transistor, Ge ungettered	0.88	340	

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Transistor, silicon, bipolar	1.77	340	With metal penetration into Si.
Transistor, silicone mesa, 2N560	2.16	339	50% failure. See Note 14.
Transistors, silicon, typical	0.96	340	$t_{[illegible]}$ lifeline. See Note 14.
Transistors, silicon, typical	1.11	340	t_{50} lifeline. See Note 14.
Transistors, submarine-cable	1.30	157	0.025% failure. See Note 14.
Transistors, submarine-cable	1.24	129	50% failure. See Note 14.
Transistors, 2N559, vacuum baked.	0.89	750	Median life based on failure criteria of collector breakdown voltage and reverse current, and emitter breakdown voltage. See Note 14.
Transistor, Vycor gettered germanium, 2N559.	1.02	339	50% failure. See Note 14.
Viton A (DuPont)	1.11	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Wire, aircraft, Type I, Size 14	1.66	360	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft. Type II, Size 8	1.77	368	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type II, Size 14.	1.56	368	MIL-W-4086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 14.	1.57	368	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 8.	1.96	368	MIL-W-5086A. Average life. See Notes 10 and 14.

QUALIFIED EQUIPMENT - SPECIFIC EXAMPLES

- TERMINAL BLOCKS
- LIMIT SWITCHES
- SOLENOID OPERATED VALVES
- TRANSMITTERS
- SPLICES AND TERMINATIONS

TERMINAL BLOCKS

PRINCIPAL MANUFACTURERS OF QUALIFIED BLOCKS

°	GE	EB-5,25
°	WESTINGHOUSE	
°	BUCHANAN	224, 524
	CURTIS	Type L
°	MARATHON	300, 1500, 1600, 1600NUC, 6000
°	KULKA	
°	WEIDMULLER	
°	STATES	

CONSTRUCTION, MATERIALS (Size, Shape, SOLID/SEGMENTED)

INSTALLATION (ENCLOSURES, ORIENTATION, MOUNTING)

PROBLEMS

FAILURE MODES

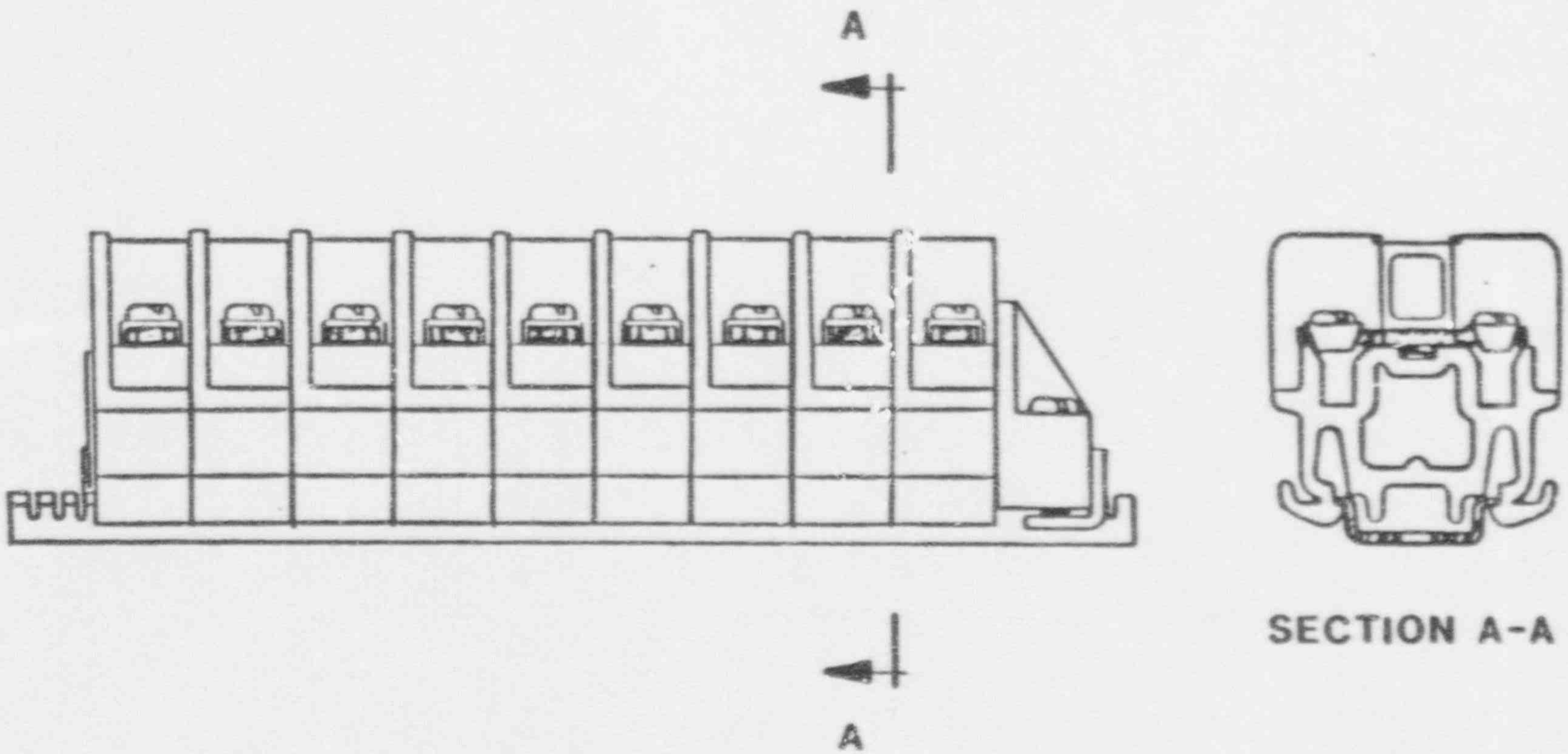


Figure 2-2: Typical Configuration for a Sectional Terminal Block

TERMINAL BLOCKS

REPORTS

INDIVIDUAL MANUFACTURERS SPONSORED

LICENSEE SPONSORED

JOINT TESTS - LIMITORQUE B0119

SANDIA REPORTS (CRAFT)
INDUSTRY ASSESSMENT - NRUEG/CR-3691
SANDIA SCREENING TESTS - NUREG/CR-3418

PERFORMANCE REQUIREMENTS/ACCEPTANCE CRITERIA

FAILURE MODES

OPERABILITY EVALUATIONS (GL 86-15)
FUNCTION PRIOR TO FAILURE
NO SAFETY DEGRADATION FROM FAILURE
OPERATOR NOT MISLEAD

ANOMALIES/PROBLEMS

IE&INS

84-73 (IN LIMITORQUES) SMC-04's BEAU 6000

82-03 GE & STATES

83-72 BUCHANAN

84-47 KULKA

~~84-78~~

Table 3-1 (continued)
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohmmeter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
WPPSS/Wyle (Norco)	Weidmuller JAK Types (same TBs as tested by Weidmuller, Ref. 3)	5	1 A Leakage current monitored by fuse and discrete time monitoring of leakage currents.	600 Vac 20 A	None	$1.2x10^5$ to $5.0x10^{10}$	Measured leakage current during test. Test was only a post-test LOCA soak. 230°F and 20 psig, 100% relative humidity. No steam.	32 d	18
Generic/ Wyle (Norco)	Phonix SSK Series Ceramic KEK Series Ceramic SSK Series Melamine K Series Polyester (2 Types)	30 units exposed to LOCA	None specified	420 Vac 20 A 48 Vdc 24 Vdc	None Reported		2 superheated steam periods. No leakage current measurements of DC circuits. < 40 mA to > 700 mA current observed in 420 Vac case	24 hr	19
Commonwealth Edison/Wyle (Huntsville)	Marathon Series 6000 Series 1600	2 2	Leakage current less than 10 A. Monitored by fuse.	175 Vac 15 A	None	$< 1.6x10^6$** to $2.2x10^{12}$ at 500 Vac **Off scale low. Measurement with Digitial Multimeter read 3.6 ohms	Some periods of superheat in accident exposure. One block exceeded 10 A leakage current--shorted to ground.	36.9 hr	20
Generic/ Westinghouse	Curtis BT Cinch Jones 541 Westinghouse 542-247 Marathon 1500		None Specified	600 Vac	$8x10^3$ to $5x10^5$	$2x10^{10}$ to $2.3x10^{11}$	Leakage currents not monitored during test with blocks powered.	≈ 21 hr	21

*FRC = Franklin Research Center

QUALIFIED EQUIPMENT - SPECIFIC EXAMPLES

- TERMINAL BLOCKS
- LIMIT SWITCHES
- SOLENOID OPERATED VALVES
- TRANSMITTERS
- SPLICES AND TERMINATIONS

TYPES

USES

MANUFACTURERS

QUALIFIED MODELS

INSTALLATION

REPORTS

PERFORMANCE REQUIREMENTS

FAILURE MODES { ACCIDENTS
TYPE OF ELECTRICAL FAULTS

OPERABILITY EVALUATIONS

REPORTS

ANOMALIES/PROBLEMS

TEST REPORTS

10CFR 21

50.72 IM. NOTIF. NRC PT 21/50.55(e) D.B.

50.73 LER

50.55(e)

IE B's

IE IN's

VENDOR NOTIFICATIONS

e.g. GE's SIL's, SAL's, PRC's, GERMAIN TO SAFETY

ROCKBESTOS LETTER ON ISOMEDIX

TERMINAL BLOCKS

PRINCIPAL MA..UFACTURERS OF QUALIFIED BLOCKS

- ° GE — EB-5,25
- ° WESTINGHOUSE
- ° BUCHANAN — 224, 524
- CURTIS — Type L
- ° MARATHON — 300, 1500, 1600, 1600NUC, 6000
- ° KULKA
- ° WEIDMULLER
- ° STATES

CONSTRUCTION, MATERIALS (Size, Shape, SOLID/SEGMENTED)

INSTALLATION (ENCLOSURES, ORIENTATION, MOUNTING)

PROBLEMS

FAILURE MODES

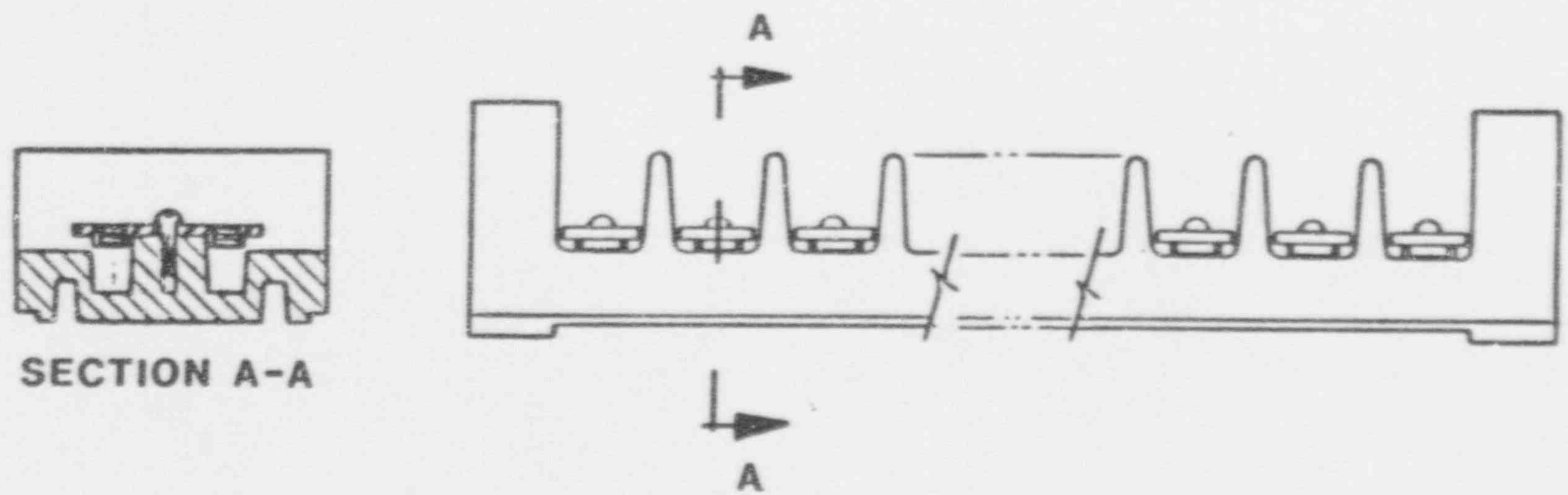


Figure 2-1: Typical Configuration for a One-Piece Terminal Block

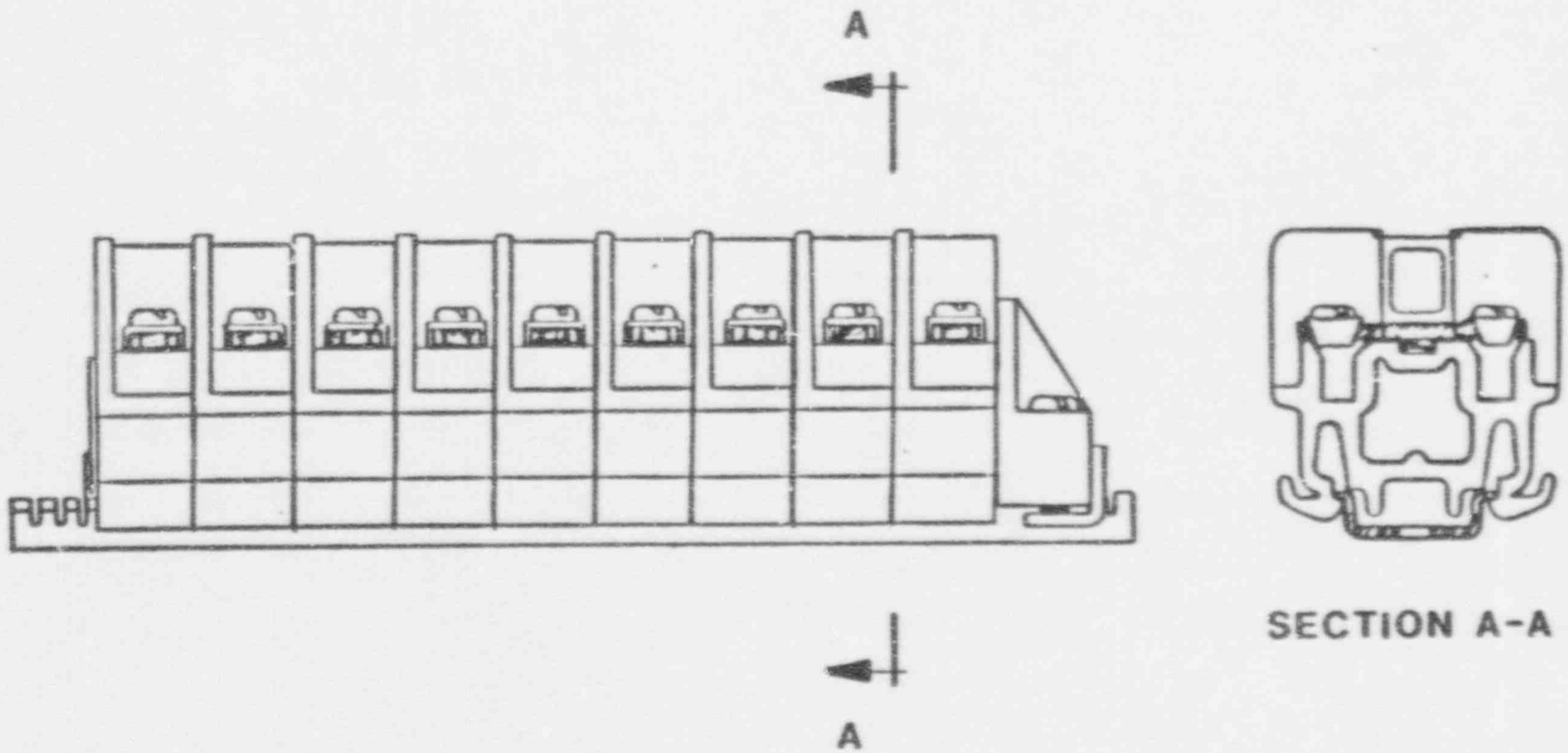


Figure 2-2: Typical Configuration for a Sectional Terminal Block

TERMINAL BLOCKS

TYPES

SOLID OR SECTIONAL (SEGMENTED)

USES	SERVICE	VOLTAGE
POWER	MOVs	480/240VAC
CONTROL	SOVs, MOVs, DPISs, LSs, PSs, TSs	120VAC/125VDC
INSTRUMENTS	FT,PT,LT,TEs	<50VDC

HOW USED - CONNECTING DEVICE LEADS TO FIELD-RUN CABLE - TO OTHER CKTs OR EPAs

MANUFACTURERS

INSTALLATION

- ENCLOSURES (e.g., NEMA-4)
- ORIENTATION
- MOUNTING

ADVANTAGES/DISADVANTAGES

TERMINAL BLOCKS

REPORTS

INDIVIDUAL MANUFACTURERS SPONSORED

LICENSEE SPONSORED

JOINT TESTS - LIMITORQUE B0119

SANDIA REPORTS (CRAFT)
INDUSTRY ASSESSMENT - NRUEG/CR-3691
SANDIA SCREENING TESTS - NUREG/CR-3418

PERFORMANCE REQUIREMENTS/ACCEPTANCE CRITERIA

FAILURE MODES

OPERABILITY EVALUATIONS (GL 86-15)
FUNCTION PRIOR TO FAILURE
NO SAFETY DEGRADATION FROM FAILURE
OPERATOR NOT MISLEAD

ANOMALIES/PROBLEMS

IEB/IN's

84-73 (IN LIMITORQUES) SMC-04's BEAU 6000

82-03 GE + STATES

83-72 BUCHANAN

84-47 KULKA

~~84-78~~

Table 3-1
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohmmeter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
Philadelphia Electric/ FRC*	Buchanan 2B104 2B108	 2 4	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$<5 \times 10^4$ at 50 Vdc	10^2 to 10^{12}	One block removed from test at 4.9 days. Others removed at various times.	14 d	14 Phase A
Philadelphia Electric/ FRC*	Buchanan 2B108 Marathon 1608	 3 2	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$<5 \times 10^5$ at 50 Vdc	$<5 \times 10^4$ at 50 Vdc to $<5 \times 10^5$ at 50 Vdc	One TB removed from from test after 5.1 hours.	7d	14 Phase B
Generic/ FRC*	Buchanan MQB106 MQB112 MQB106S MQB112S MQO Series	 1 1 [illegible] 1 3	Maintain potential of 120 V and current of 25 A.	120 Vac 25 A	$<5 \times 10^4$ at 10 V to 2×10^{12} at 500 V	Post-test hipot test	During LOCA, leakage currents were < 200 mA to < 5 mA for all terminal blocks together.	7 d	15
Generic/ Wyle (Huntsville)	Marathon 1600 NUC 1500 NUC 142 NUC	 6 6 6	Leakage currents less than 12 A, or 18 A, or 24 A. Monitored by fuse.	132 Vac, 33 A 264 Vac, 33 A 528 Vac, 33 A	None	$<5 \times 10^5$ for all 528 V boxes	Blew 25 A fuse on 528 Vac specimens. Removed from test. Blew 18 A fuse on 264 Vac specimens. Replaced fuse and continued.	30 d	15
Generic/ FRC*	Weidmuller SAK Types	5	Maintain 600 Vac and 20 A with leakage current less than 1 A. Monitored by fuse.	600 Vac 20 A	None	2.4×10^7 to 3.5×10^8 at 500 Vdc	Voltage reduced to 150 V when spray introduced to maintain leakage current less than 1 A.	29 hr	17

*FRC = Franklin Research Center

Table 3-1 (continued)
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohmmeter Measurements (ohms) (500 Vdc unless noted) During LOCA	Megohmmeter Measurements Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
WPPSS/Wyle (Norco)	Weidmuller SAK Types (same TBs as tested by Weidmuller, Ref. 3)	5	1 A Leakage current Monitored by fuse and discrete time monitoring of leakage currents.	600 Vac 20 A	None	$1.2x10^5$ to $5.0x10^{10}$	Measured leakage current during test. Test was only a post-test LOCA soak. 230°F and 20 psig, 100% relative humidity. No steam.	32 d	18
Generic/ Wyle (Norco)	Phonix SSK Series Ceramic KEK Series Ceramic SSK Series Melamine K Series Polyester (2 Types)	30 units exposed to LOCA	None specified	420 Vac 20 A 48 Vdc 24 Vdc	None Reported		2 superheated steam periods. No leakage current measurements of DC circuits. < 40 mA to > 700 mA current observed in 420 Vac case	24 hr	19
Commonwealth Edison/Wyle (Huntsville)	Marathon Series 6000 Series 1600	2 3	Leakage current less than 10 A. Monitored by fuse.	175 Vac 15 A	None	$< 1.6x10^6$** to $2.2x10^{12}$ at 500 Vac **Off scale low. Measurement with Digital Multimeter read 3.6 ohms	Some periods of superheat in accident exposure. One block exceeded 10 A leakage current--shorted to ground.	36.9 hr	20
Generic/ Westinghouse	Curtis BT Cinch Jones 541 Westinghouse 542-247 Marathon 1500		None Specified	600 Vac	$8x10^3$ to $5x10^5$	$2x10^{10}$ to $2.3x10^{11}$	Leakage currents not monitored during test with blocks powered.	≈ 21 hr	21

*FRC = Franklin Research Center

Table 7-1

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Gross Electrical Breakdown (e.g., low resistance path terminal-to-terminal or terminal-to-base plate	Low Voltage Surface Breakdown*	Environmental Conditions High Temperature Humidity/Moisture Contaminants	Voltage Exposure Time	Loss of Circuit Operability	Temporary
			Insulation Type		
		Volatile/Soluble Surface Contamination	Contaminant Deposition Rate		Temporary
		Radiation	Aging Normal Accelerated		
		High Leakage Currents and Surface Tracking			
		Non-Volatile Surface Contamination	Corrosion Products		Permanent
			Conductive Residue		
	Conducting Path	Thermal and/or Pryolytic Decomposition of Insulation	High Temperature	Loss of Circuit Operability	Permanent
			Exposure to Burning Environment		
		Structural Failure	Excessive Temperature	Cracking of Insulation	Permanent
			Excessive Thermal Shock		
			Vibration		

* High voltage breakdown not included due to lack of HV circuits in nuclear applications

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Gross Electrical Breakdown (continued)	Conducting Path (continued)	Structural Failure (continued)	Improper Maintenance		
			Improper Installation		
			Aging		
	Bulk Insulation Breakdown	Radiation			
		Moisture Absorption Cracking	Moisture Absorption	Splitting of insulation and formation of conducting paths	
Leakage Currents	Surface Conduction	Surface Contamination	Installation Practices	Low Frequency Line Noise	Some leakage will always occur. The question is a matter of degree. Leakage of a few milliamperes may be detrital to an instrumentation circuit, but have no effect on a power circuit.
		Environmental Conditions (e.g., High Temperature Humidity/Moisture, Contaminants)	Maintenance Practices	Circuit Crosstalk	
			Voltage Level	Excessive Power Drain	
			Aging	Biased Readings on Instrument Outputs	
		Radiation	Access for beta-emitting isotopes	Gross Breakdown	

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Leakage Currents (continued)	Surface Conduction (continued)	Structural Failure	Excessive Temperature	Cracking of insulation	
			Excessive Thermal Shock		
			Vibration		
			Improper Maintenance		
			Improper Installation		
Open Circuit	Separation of Conductor	Loose Terminal Screws		Loss of Circuit Operability	
		Contact Corrosion	Chemical Reagents		
			Moisture/ Humidity		
		Structural Failure	Vibration	Cracking of Conductor	
			Thermal Shock		
			Improper Maintenance		
			Improper Installation		
			Differential Expansion		

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Open Circuit (continued)	Separation of conductor (continued)	High Leakage Currents			
		Failure to Reconnect Terminals	Careless Maintenance Procedures		
			Lack of Quality Assurance		

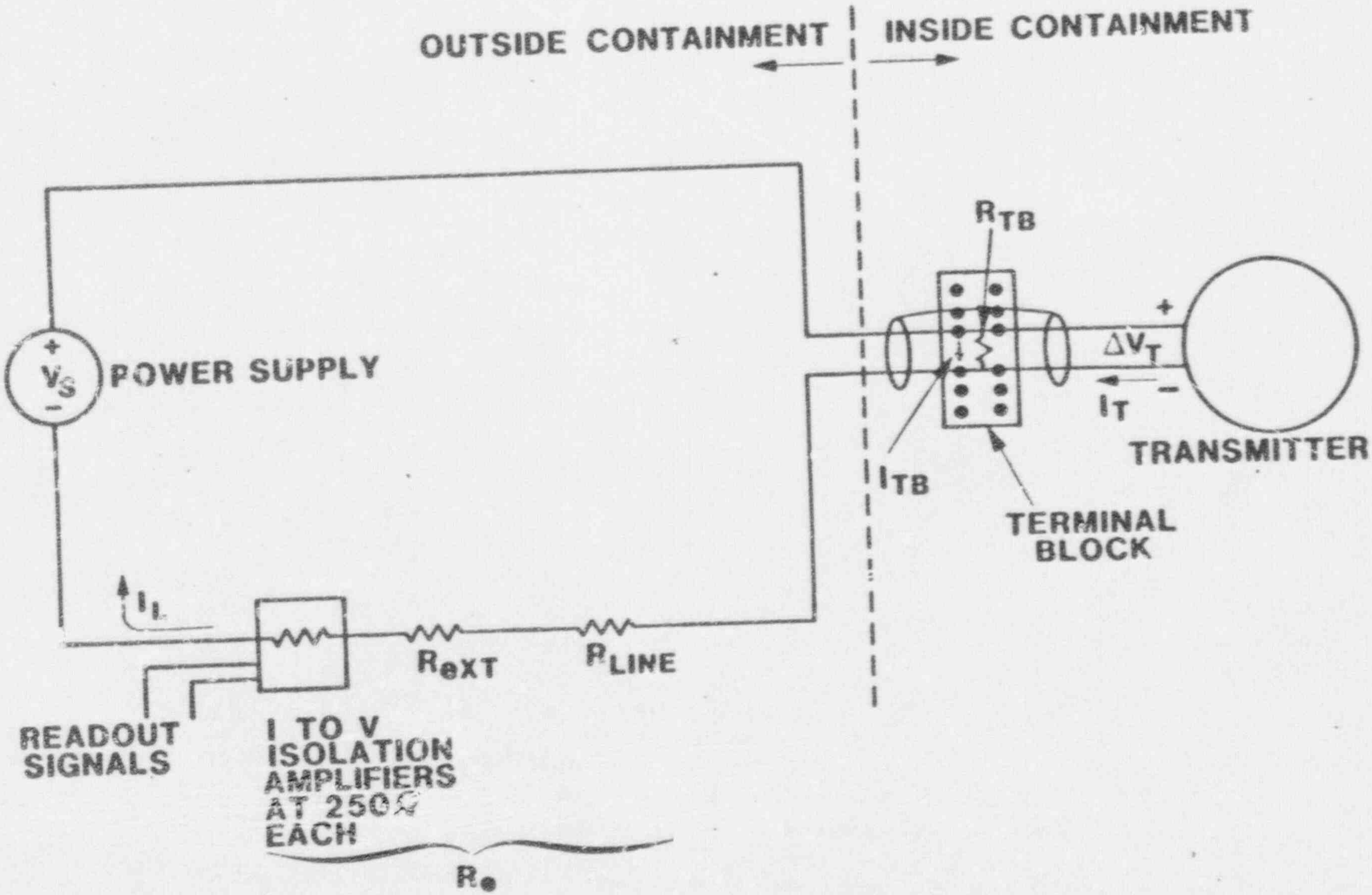


Figure 8-1: Simplified Schematic of a Typical Transmitter Circuit in a Nuclear Power Plant

-87-

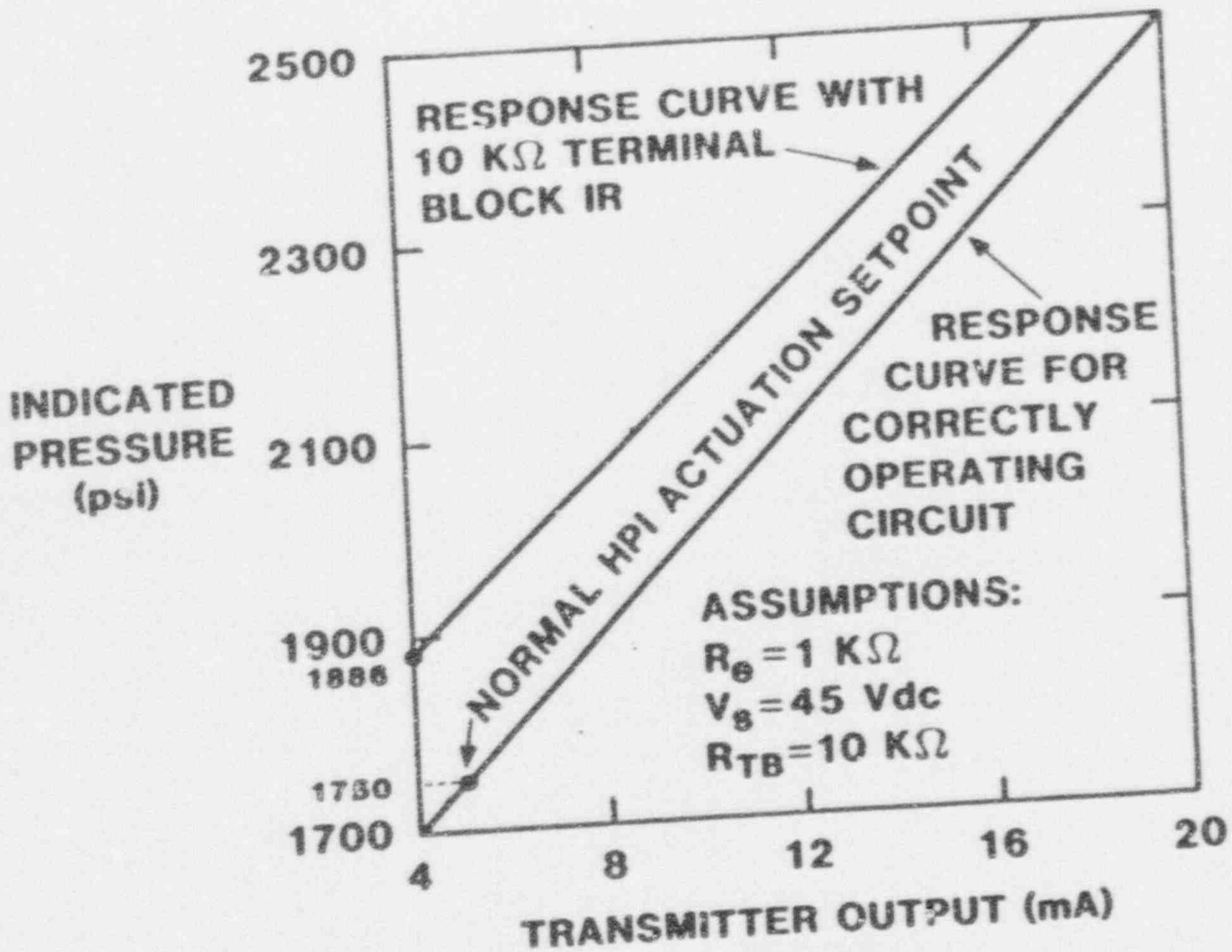


Figure 6-4: Indicated Pressure as a Function of Transmitter Output for a Correctly Operating Circuit and for a Circuit With Terminal Block Insulation Resistance Assumed to be 10 kohms

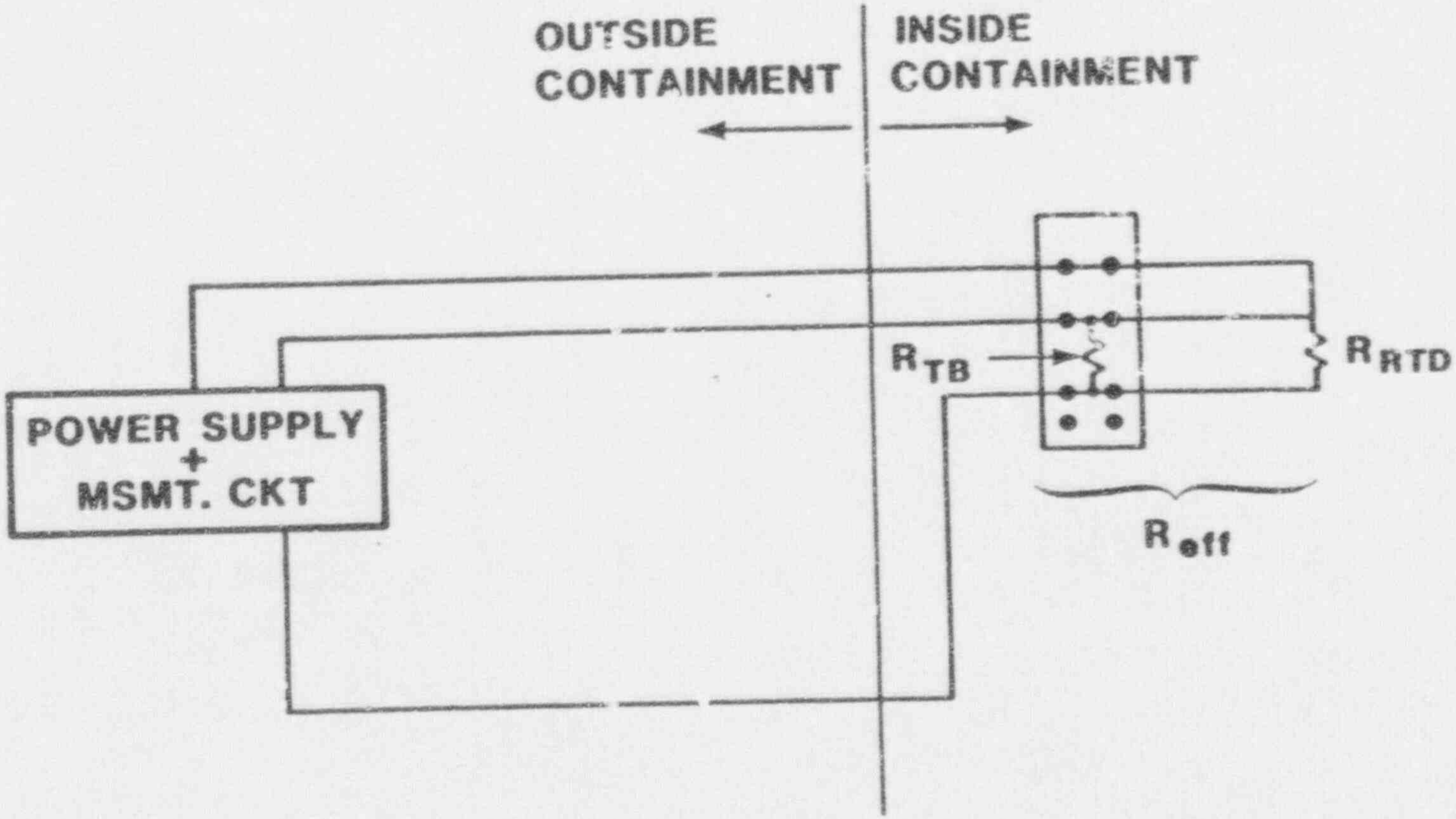


Figure 8-5: Simplified Block Diagram of a 3-Wire RTD Circuit Showing Parallel Connection Between Terminal Block Insulation Resistance and the Resistance of the RTD Sensing Element

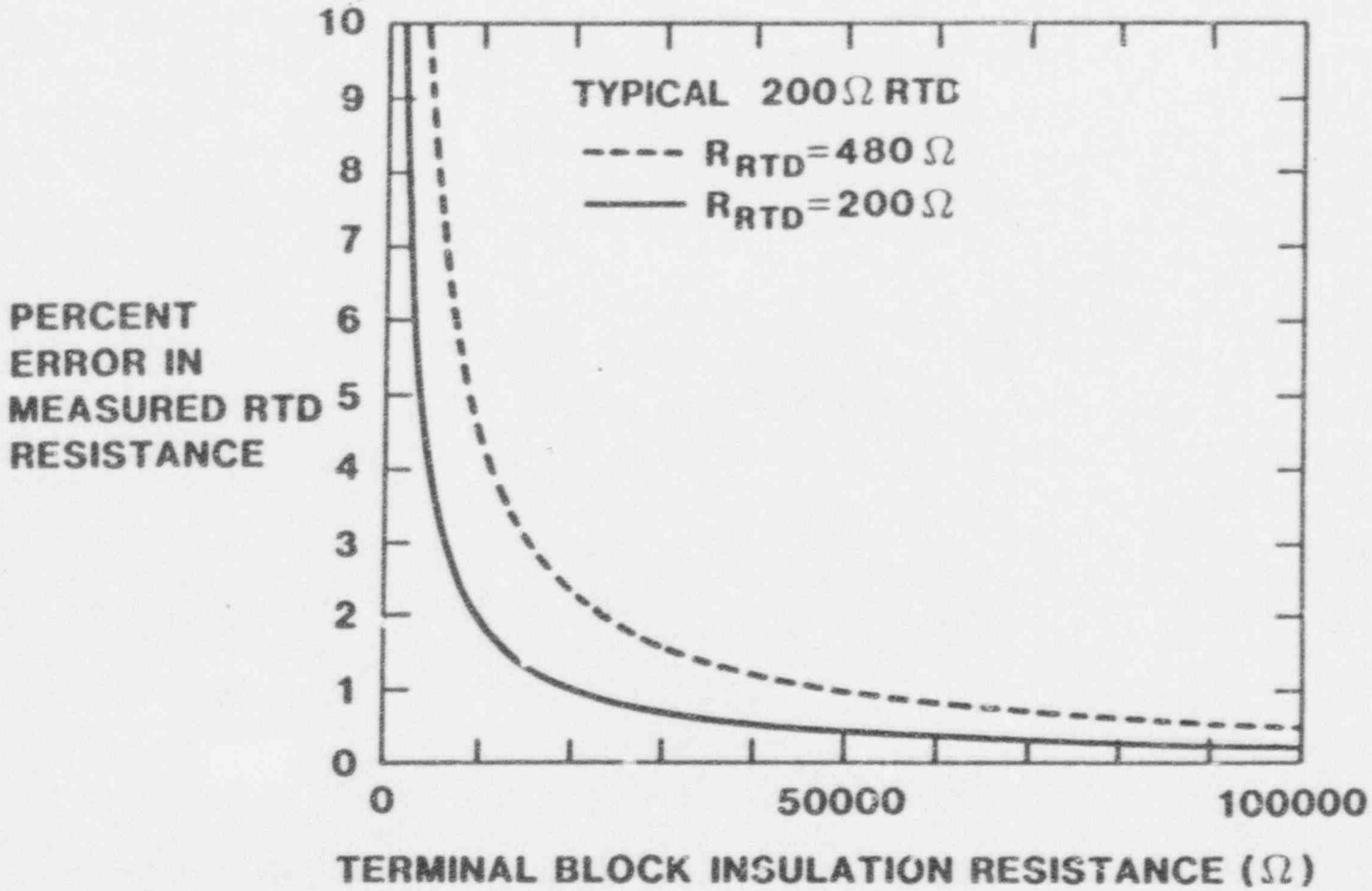


Figure 8-6: Percent Error in the Resistance Measurement of an RTD as a Function of Terminal Block Insulation Resistance

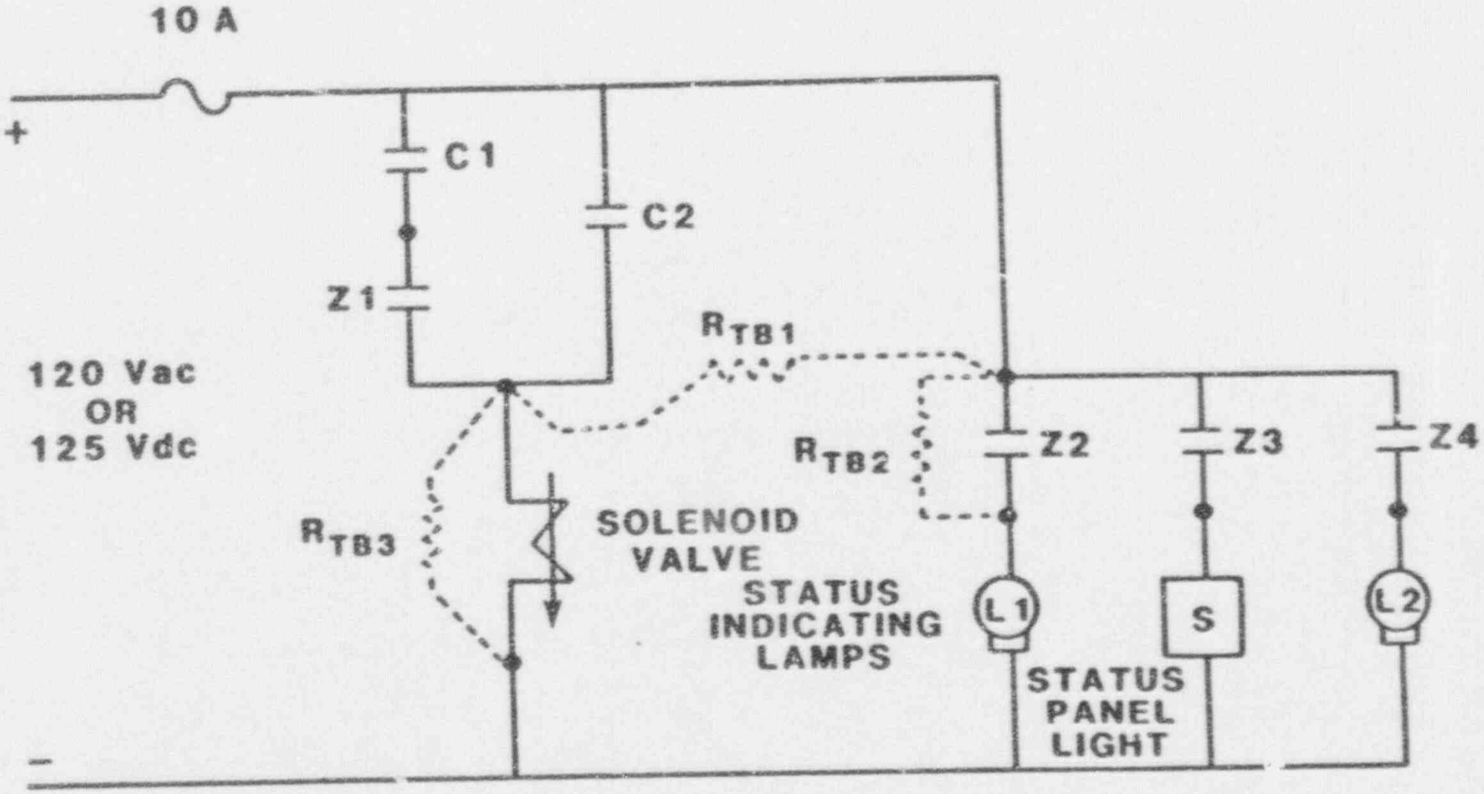


Figure 8-12: Simplified Circuit Schematic for One Possible Solenoid Valve Circuit

11.0 CONCLUSIONS

1. The primary application of terminal blocks in the nuclear power industry is instrumentation and control circuits.

2. Terminal blocks receive minimal quality assurance attention in selection, installation, inspection and maintenance activities.

3. Most industry qualification tests do not continuously monitor for low level leakage currents during LOCA simulation tests of terminal blocks. Without quantitative knowledge of these leakage currents, adequate analyses of their effects on instrumentation and control circuits cannot be performed.

4. Surface moisture films are the most probable explanation for degradation in terminal block performance during exposure to a steam environment. Because the existence of moisture films is highly dependent upon environmental conditions, test environments must realistically reflect the predominantly expected accident environments. For example, superheated test conditions may not accurately represent the terminal blocks' performance.

5. The use of voltage levels above actual use conditions in qualification tests of terminal blocks may be nonconservative with respect to the measurement of low level leakage currents which are the primary degradation mode of terminal blocks.

6. Terminal block leakage currents in a steam environment may degrade performance of instrumentation and control circuits to an extent sufficient to cause erroneous indications and/or actions.

7. Cleaning will probably not reduce leakage currents to a level acceptable for most instrumentation and control applications. The large, positive impact on terminal block performance that was originally believed to accrue from cleaning was not observed. Further, terminal block leakage currents were not significantly reduced by the application of either of two coatings tested.

PROBLEM TERMINAL BLOCKS

MARATHON 1600

TEST SUMMARY

PARAMETER	LIMITORQUE	WYLE/MARA.	WYLE/PP&L	WYLE/CECo
REPORT NO.	B0119	45603-1	45822-00	17657
DATE	APR 82	FEB 82	FEB 87	DEC 83
RADIATION	2.0E8	2.0E8	2.0E8	2.0E8
MOUNTING	UPRIGHT	FLAT	FLAT	FLAT
ENCLOSURE	DUMMY MOV	NEMA-4	NEMA-4	NEMA-4
AGING TEMP	280°F	248°F	248°F	248°F
AGING TIME	300 HR	443 HR	185 HR	932 HR
LOCA TEMP	312°F	350°F	360/330°F	345°F
PEAK TIME	30 MIN.	3 HR	3 HR/3 HR	
VOLTAGE	250-2.8VDC MEGGER	132/264/528 CONTINUOUS	528VAC INTERMITTENT*	42/135DC/132AC CONTINUOUS
FPR/ACPT	>300IR	12/18/~~20~~ 25A FUSE	FUSES	LKG
RESULTS	INCONCL	FAIL	FAIL	HIGH LKG

* FUNCTIONAL CHECK WITH SMALL MOTOR LOAD

OTHERS

IEB's & IN's

IN 83-72 BUCHANAN

IEB 82-04 BUNKER RAMO EPA (KULKA)

950 Ω

TERMINAL BLOCKS
MARATHON
CRAFT REPORT

REPORT	DATE	AGING TEMP/TIME	DBE TEMP/TIME	FUSES LINE/LKG	RESULTS

WYLE-MARATHON 45603

WYLE-PP&L FEB87

WYLE-CECO 17657

LIMITORQUE B0119

SAFETY RELATED FROM MARATHON HAS STICKER. H.B. SAYS DIFFERENT FROM 1600s SUPPLIED TO LIM. COMM. GRADE.

ANOMALIES:

45603: cont. energ.,528 fail, 264 blew-not clear when replaced, 132 OK till near end of test when on restoratiuon of power, all blew!

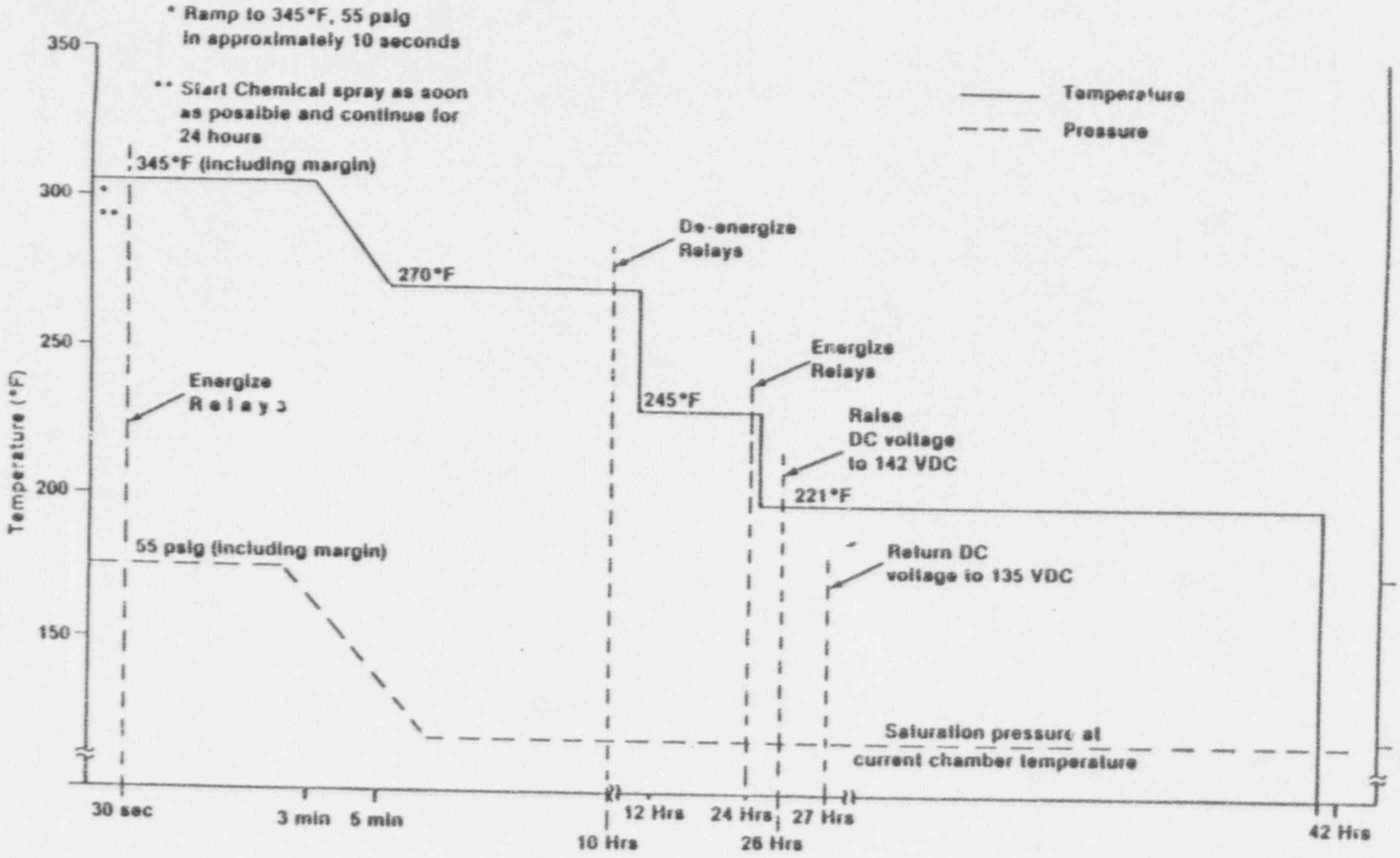
PP&L-1600s only, three, horiz failed on enrgizing after spray init.

B0119-only one 300 energ. althcugh intermittently (worst case)
Curtis L data mis reported 700 ohm vice 700K
IRs taken wiyh as low as 2.8 VDC (500 V Megger)

NOte TBs mounted vertically out from base

HOW TO EVALUATE OPERABILITY ANALYSES

VOLTAGE DIVIDERS
FUSES
CONTINUOUS OPERATION
FAILURE MODES AND EFFECTS



ACCIDENT TEST PROFILE
Figure 3

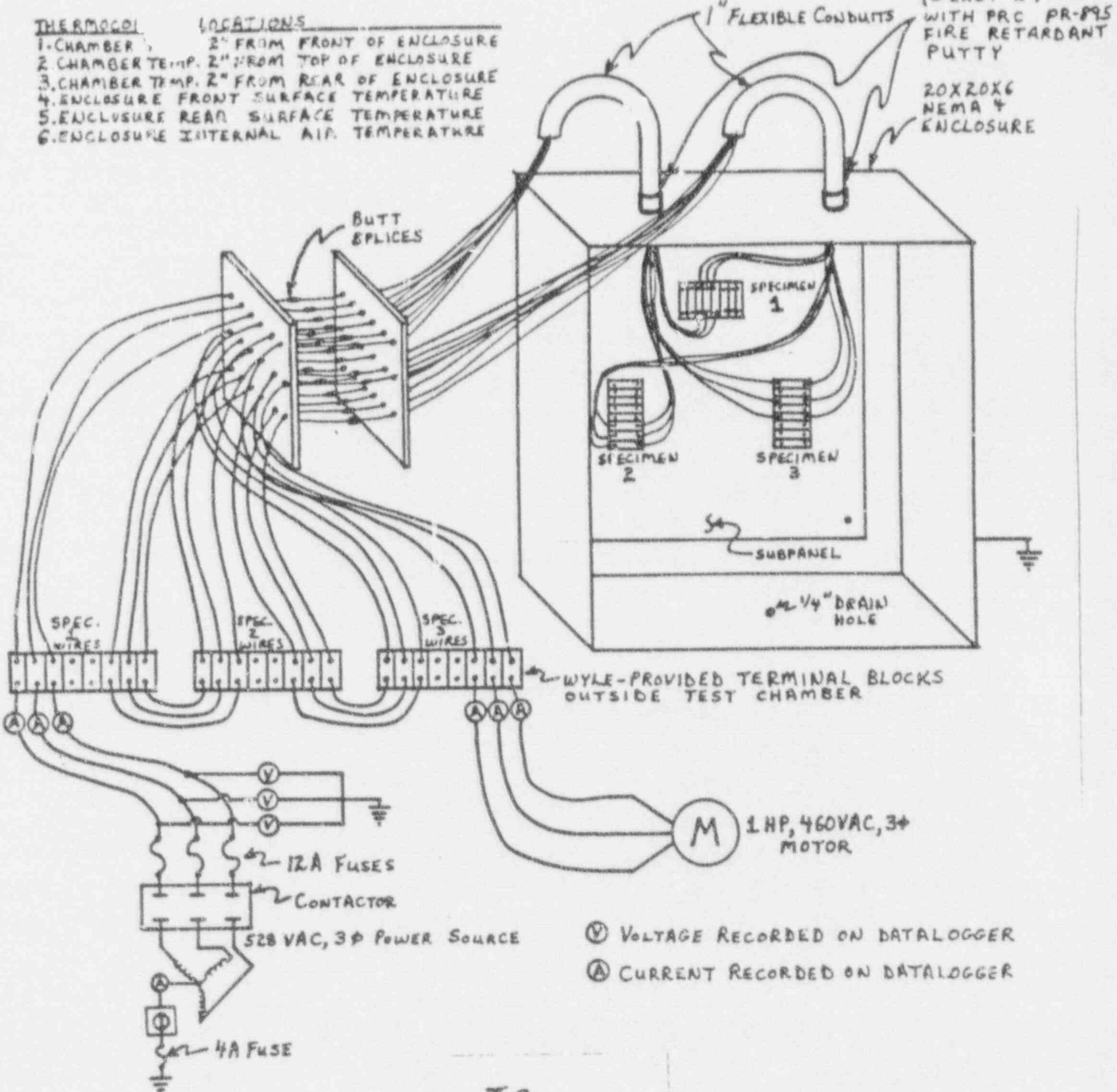


Figure X-2
Terminal Block
Accident Test
Setup

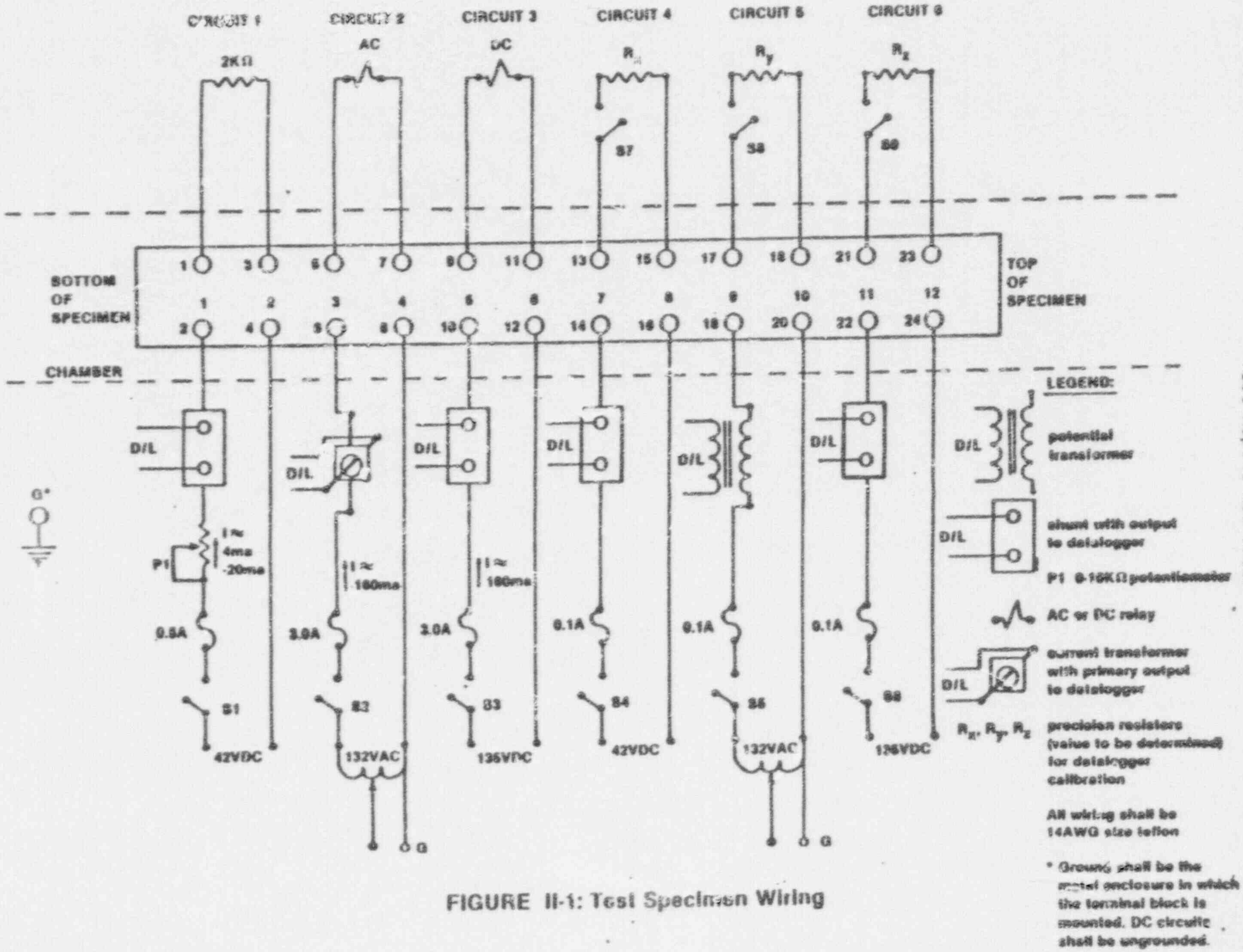


FIGURE II-1: Test Specimen Wiring

Test Report No. 17657

Table 2-1

Typical Radiation Damage Thresholds and Maximum Service Temperatures for Five Insulating Materials Used in Terminal Blocks Found in U.S. Nuclear Power Plants

Insulating Material	Radiation Damage Threshold (Rads(C)) [6]	Service Temperature °C (°F) [7]
Phenolics		
glass filled	10^{10}	160-190 (320-374)
cellulose filled	10^{8}-10^{9}	120-220 (248-428)
Alkyd		
glass filled	10^{9}	149-191 (300-376)
cellulose filled	10^{8}	191 (376)
Melamine (Resin)	10^{8}	
glass filled	10^{9}	204 (399)
cellulose filled	10^{7}	99-150 (210-302)
Diallyl Phthalate		
glass filled	10^{8}	204 (399)
cellulose filled	10^{7}	160 (320)
Nylon 61	10^{5}-10^{6}	130 (266) [8]

glass), the radiation levels quoted in Table 2-1 indicate that there will be minimal effect on the insulating materials normally used for terminal blocks by nuclear plant radiation doses (estimated doses: 5×10^{7} rad operating life and estimated 1.5×10^{8} rad accident).

The metallic terminals are typically stable to temperature and radiation levels which exceed the aging and accident environments postulated for nuclear power plants. Thus, we would not expect degraded performance of the conducting material based on pure radiation and/or temperature effects. There is, however, potential for material interaction problems such as corrosion or galvanic action to occur. The selection of metal coatings and base conductor material should be such that these effects are minimized in both the normal operating environment (e.g., 80-110°F and 10-100% RH) and the postulated accident environments which include steam and chemicals. One specific example would be to avoid the use of cadmium as plating material because in a steam-chemical spray environment it may be a reactant in a galvanic reaction.

KULKA MODEL 602JJ TERMINAL BLOCKS

AMPHENOL REPORT 123-2222

10 ma FUSE IN LEAKAGE CKT BLEW
DURING SECOND LOCA PEAK (340°F)

HAD TO REDUCE VOLTAGE FROM 600VAC
TO 370VAC TO KEEP FUSE FROM BLOWING

RETURNED TO 600VAC ON DAY 7

ANOMALIE NOT EXPLAINED

IRs AS LOW AS 100 OHMS AT 370VAC

NOT ENOUGH INFO TO RESOLVE IR NOR
ANALYSIS TO SHOW OPERABILITY OF
SERVED EQUIPMENT

ANOMALOUS SAMPLES AGED

OTHERS NOT AGED

6. <u>Terminal Blocks, Raceways and Enclosures - EQ Concerns</u>

(TB) - Installed directly below top conduit entries in boxes without adequate test documentation for leakage current

(Anchor Darling) - Unqualified Nylon TBs. Unqualified for temperature.

(Anaconda Conduit) - Polyethylene copolymer jacket of flex conduit degraded while exposed to LOCA conditions (IN No. 83-72).

(Marathon) - 1600 Series TB found unqualified for circuits over 264 VAC in the drywell (In general there are no qualified TB's for 480V applications in the drywell).

(Stanwick) - Corroded terminals affecting qualified life. Junction boxes dirty and corroded.

LIMIT SWITCHES

TYPES - DOUBLE ACTING / SINGLE
-

USES - VALVE / DAMPER POSITION INDICATION

PRINCIPAL MFGRS

NAMCO CONTROLS — REPORTS HAVE MATERIAL CHANGE HISTORY BY DATE CODE

GASKETS - VELEMOID / SR

QUALIFIED MODELS

EA180 QTR 105 323-74

EA170 QTR 107 RAD'N ONLY 200 MRAD

D2400X PREDESSOR OF EA170

EA740 323-74
EA750 200 MRAD + SEIS (344-75)
EA700 SEIS ONLY

INSTALLATION
- GASKETS — MODEL NO.
- ECSA'S — CONFIGURATION SUFFIX
- NYLON ROLLERS — DATE CODE

IR'S SHUNTING OPEN CONTACTS

MICRO SWITCH DPST, 12 TSI-2 IN 33-72

LIMIT SWITCH PHYSICAL INSPECTION CHECKLIST

Component ID ____________________ Reviewer: ______________________

Documented Information	Installed Condition: Agrees with Documented — Yes	No	Comments
1. Location Bldg. ____ Room ____ Elev ____	___	___	
2. Manufacturer ____________________	___	___	
3. Model No. ____________________	___	___	
4. Mounting Description __________ ____________________________	___	___	
5. Orientation ____________________ ____________________________	___	___	
6. Electrical Connection Type _____	___	___	
7. Housing Seals in Good Condition	___	___	
8. Ambient Normal Expected Temperature Range __________	___	___	(If ambient temperature exceeds normal expected conditions, verify that licensee has considered the elevated temperature in the qualified life evaluation)

General Comments on Physical Inspection:

Issue Date:

9. <u>Position Switch/Limit Switch/Push Button Switches - EQ Concerns</u>

- (NAMCO) - Lacked cable entrance seal
- (NAMCO) - Cover screws missing - Bad housekeeping
- (REES) - Push button - Lacked test report and evaluation for ambient pressure

SOLENOID OPERATED VALVES

TYPES/USES - AC, DC, SINGLE SOL. / DBL SOL.

2 WAY, 3 WAY

ENERGIZED TO OPEN/CLOSE - VENT

N.E. N.D.

N.O. N.C.

FCV's

FCPV's

DEGRADABLE PARTS

ELASTOMERS - DIAPHRAGMS

- O-RINGS - PLUNGER SEALS

- COIL WIRE INSULATION

PRINCIPLE MANUFACTURERS

QUALIFIED MODELS

ASCO

AUTOMATIC SWITCH CO.

NP-1

206381

ELASTOMERIC SUFFIX

"V" for VITON ← degradation at 70 Mrads oil in system

E for EPDM

↑ Better Rad properties

IN 84-28 Energized coils have an 135°F increase in temp

VALCOR

TARGET ROCK

DRESSER

LAWRENCE

Seitz

ECSA's

SUBMERGENCE

SEALANTS - PIPE THREAD ETC

VENTS

SOV's

IN's 80-11 ASCO

82-52 DRESSER

TARGET ROCK

CCI

ASCO

84-23 ASCO

84-68 VALCOR, TGT ROCK

85-08 ASCO

85-17 ASCO → HTX-8323

ASCO REPORTS

7/79 ,80

TR No. AQS 21678/TR RE. A & B

323-74

382-72 NP-1-206381

(8300's)

30 DAY LOCA 346°F PEAK

TR No. AQR-67368 1982

323-74

30 day LOCA/HELB + MARGIN 420°F

PT 21 SALEM 206-381-6RU - INCORRECT SEATS

SOLENOID OPERATED VALVE PHYSICAL INSPECTION CHECKLIST

Component ID ________________ ...iewer: ____________________

	Installed Condition		
	Agrees with Documented		
Documented Information	Yes	No	Comments
1. Location Bldg. ___ Room ___ Elev ___	___	___	
2. Manufacturer ______________	___	___	
3. a. Model No. ______________	___	___	
b. Voltage ______________	___	___	
c. Configuration ______________	___	___	
4. Mounting Description ________	___	___	
5. Orientation ______________	___	___	
6. Process Connection Type _____	___	___	
7. Electrical Connection Type __	___	___	
8. Housing Seals in Good Condition	___	___	
9. Does Installed Device Experience a Significant Temperature Rise from Process?	___	___	(If yes, documentation must be reviewed to determine if the temperature rise was considered)
10. Ambient Normal Expected Temperature Range _________	___	___	(If ambient temperature exceeds normal expected conditions, verify that licensee has considered the elevated temperature in the qualified life evaluation)

General Comments on Physical Inspection:

Issue Date:

4. Solenoid Valves - EQ Concerns

(ASCO) - Coil replacement interval exceeded.

(ASCO) - File required conduit entrance seal for valves under high pressure; no seals found in field.

(ASCO) - File required sealed cable conduits with weep holes at low point; not found in field.

(ASCO) - Loose housing found which could allow the atmosphere to enter coil housing.

(DRESSER) - Valve Model No. 1525VX had unqualified PVC wire (No documentation)

(ASCO) - Model No. NP-8316-54V not qualified by type test, in that moisture seals were not provided at the cable entry.

(TARGET ROCK) - Internal temperature rise causing temperature of field run cable to exceed rating (IEB No. 84-68).

(ASCo) - File stated that all solenoid valves (ASCo) had to be tested once a month to insure proper opening and closing; while maintenance instructions said no maintenance was required.

(ASCo) - Valve containing viton dynamic seals, ASCo Model No. NP1, not to shift position after being exposed to > 20 MRads (IN No. 82-52).

(ASCO) - Model NP-1 has ethylene propylene seal elastomers that degrade when exposed to oils and greases (IEB No. 80-11).

(ASCo) - Models NP 8316 and NP 8344 failed during LOCA testing at Franklin (IN No. 84-23); attributed to elastomers sticking to valve metallic parts.

TRANSMITTERS

UPIS

PS

TS

ELECTRONIC PT, LT, FT
(ANALOG)

TYPICALLY 50 VDC, 10-50 ma or 4-20 ma

ACCURACY - UNITS, PERCENT

LOOP ACCURACY - CABLE, ZPA's, TB's - IR's

$\sqrt{\Sigma IR^2}$ - RANDOM

T/E's - RTD's
- T/C's

PRINCIPAL MANUFACTURERS — QUALIFIED MODELS

BARTON — 278 279 288(A)
SW's 580 SERIES
580 SERIES

XMTR's 763 LOT 1
764 LOT 2

FOXBORO — E11 Look for NE11 for qualified series

ROSEMOUNT — 1151
1152
1153

RAYCHEM
ECSA's

(third generation or forgery)

1153 B outside
D inside

RADIATION FIELDS / TEMP

O-RINGS

TYPE OF WIRE

TRANSMITTERS (INCL. P'S:)

IN'S

82-11 W NSSS SUPPLIED HELB ERROR
WR PT

82-52 BARTON LOT 4 GRA
(W SUPP)

83-72 BARTON PART DAR-29098
BARTON 763
BARTON 764
BARKSDALE PS B2T, D2H
SOR PS 5N, 12N

TRANSMITTER PHYSICAL INSPECTION CHECKLIST

Component ID No.: ____ __________ Reviewer: __________

Documented Information	Installed Condition Agrees with Documented Yes	No	Comments
1. Location Bldg. ____ Room ___ Elev ___	___	___	
2. Manufacturer __________	___	___	
3. a. Model No. __________ b. Range/Type Code __________ c. Serial No. __________	___ ___ ___	___ ___ ___	
4. Mounting Description __________ __________	___ ___	___ ___	
5. Orientation __________ __________	___	___	
6. Process Connection Type ______ __________	___	___	
7. Electrical Connection Type ___ __________	___	___	
8. Housing Seals in Good Condition, Covers in Place	___	___	
9. Does Installed Device Experience a Significant Temperature Rise from Process?	___	___	(If yes, review documentation to determine whether considered)
10. Ambient Normal Expected Temperature Range __________ __________	___	___	(If ambient temperature exceeds normal expected, verify that qualified life evaluation considered)

General Comments on Physical Inspection:

Issue Date:

7. Transmitters - EQ concerns

(General) - Qualified life exceeded for parts or whole, Calibration life exceeded

(Rosemount) - Pressure, level and flow transmitters lacked conduit weepholes; had wrong location and wrong model

(Rosemount Level Transmitters) - No record of O ring replacement during maintenance.

(Rosemount 1154) - File indicated a qualified life of 15 years but maintenance requirements did not call for a replacement at that time.

(Foxboro) - Conductor insulation degradation found on Foxboro Model E Controllers, IN No. 86-52

8. Level Switch /Pressure Differential Switch - EQ Concerns

(Static-O-Ring) - (SOR) pressure switch lacked cable entrance seal

(Magnetorol) - EQ File indicated no qualification required, however, file did not address effects of switch failure on other EQ equipment.

(Static O Ring) - Series 102 and 103, erratic tripping below specified drift pressure setpoints, IEB No. 86-02, IE No. 86-47.

(Static O Ring) - DP switches exhibited erratic tripping due to corrosion of O rings also exhibited drifting setpoints (IEB No. 8602)

(Barksdale) - Pressure switches Models B2T and D2M experienced blown seals that allowed water to accumulate in the switch housing, and as a result, exhibited electrical shorts across the microswitches.

(Static O Ring) - Pressure Switches, Models 5N and 12N failed in LOCA testing due to blown in gaskets and elastrometric diaphragms rupture (IN No 83-72).

Rosemount 1153B — alternate cable seal in a seal in it

RAYCHEM SPLICES

REPORTS

TYPES - WCSF-N
- NMCK
-

CONFIGURATIONS
IN LINE
V
BREAKOUTS
BOLTED
BUTT SPLICE - INSULATED & UNINSULATED
BOOTS
OVERSLEEVES

PROBLEMS IN 86-53
OVERLAP < 2" SHIMS
BRAID PADS (BOLTS)
USE RANGE
SHRINKAGE
BENDING
SURFACE PREP
ADHEASIVE
OVERSLEEVES

INSPECTION

TI 2500/17 9/22/86

MODULE 92701 FOLLOWUPS

-INCLUDING IEN'S

CONDULET

LIMITORQUES

SMALL JCN BOXES

NUGEQ REPORT 1/4", BENT IN HALF ETC.

ANALYSIS USING NUGEQ DATA

OTHER TYPES OF SPLICE INSULATION

RTV'S

- TAPE - HV & LV

4KV 5KV → HV - KERITE WHITE NYLON WRAPPING
- OKONITE
(NEW RAYCHEM HV NMCK)
TYPICALLY ON 4KV/5KV CSPM'S, SIPM'S
RHR PM'S. ETC

LV - SCOTCH 33+ - INNER
SCOTCHCO PUTTY - FILLER DOR, 50.49(1)
SCOTCH 70 - INNER
SCOTCH 23 - OUTER PLAIN ELECTRICAL TAPE

- INSULATED BUTT CONNECTORS - AMP
NYLON, GE-F01 EPA'S - FAILED in WYLE/CECO
IN 86-104

- QUALIFIED - KYNAR

3. Cable Splices - EQ Concerns

- (Raychem WCSF-N) file did not address Beta radiation for unshielded splices.

- (AMP splices) Lack of qualification traceability for nylon insulated splices.

- (AMP splices) Found degraded prior to the end of their qualified life at Dresden.

- (Raychem) Files too general. No specific consideration for high leakage currents and low IRs affecting instrumentation circuits. No plant specific acceptance criteria identified.

- (Raychem) Report made generic qualification statement of similarity for all models; however, not clear on degree of similarity, as no discussion or analysis to support similarity existed. No reference to polymer materials of construction.

- (American Pamcor) Test report did not establish adequate similarity between tested Model No 52979 and other specific models in plant.

- (Raychem) - Less than required overlap of seal length on cable insulation.
  - Splicing over braided material/unqualified substrate.
  - Exceeding bending radius requirements of shrink tubing.
  - Use of wrong kits caused stretching of tubing and inadequate seal.
  - Lack of shims on small diameter cables.
  - Flexing of splices while hot caused damage to surface of seal.
  - Lack of QA/QC hold points.
  - Site procedures do not conform to RayChem instructions.

DATE	REPORTS NO.	AGING	RADIATION	PEAK/T[illegible]/pH (oF)	SAMPLE DESC	CABLE
1973	71106	121°C, 168 hrs	100 Mrads 200	360°F, 100 days, 10	In-Line Splice WCSF-N (6")	XLPE EPR/Neopren[illegible]
1974	FC4033-3	150°C, 168 hrs	150 Mrads 200	357°F, 30 days, 9.5 11.0	In-Line Splice (6") Transition Splice WCSF-N/-4 molded parts	XLPE
1978	EDR5019	150°C, unaged 168 hrs 1500 hrs	200 Mrads	DOUBLE PEAK LOCA 350°F, 21 days, 10.5	In-Line Splice WCSF-N (6")	XLPE
1980	EDR5011	150°C, 168 hrs	163 Mrads	DOUBLE PEAK LOCA 340°F, 30 days, 10.5	In-Line Splice WCSF-N (6") on EPR/HYPALON WIRE	EPR/Hypalon
1980	EDR5015	150°C, 168 hrs	200 Mrads	DOUBLE PEAK LOCA 340°F, 30 days, 10.5	- NMCK - Motor Connection Kit - NESK - Cable End Sealing Kit	XLPE
1981	WYLE 58442	150°C, unaged 1000 hrs 1500 hrs	200 Mrads 290	390°F, 30 days, 10.5	In-Line Splice WCSF-N ("L") NCBK - CABLE Breakout Kit NESK - END Sealing Kit NMCK - Motor Kit	XLPE
1982	WYLE 58722	150°C, 767 hrs	215 Mrads	DOUBLE PEAK LOCA 442°F, 30 days, 10.5	In-Line Splice WCSF-N (6") NPKV - Stub Connection Kit NPK - Plant Splice Kit Transition Sleeve - 202B	XLPE
1983	EDR5088	ANCi-C119.1			In-Line Splice WCSF-N (3") One Inch Seal (Non-Accident Criteria)	XLPE

EDR 6057 * [illegible]

* This list is a compilation of major qualification reports. These reports reflect the overall development of the qualification program to meet the then current industry requirements. A complete list of reports is detailed in Raychem's Nuclear Product Guide I.

WALKDOWN CONSIDERATIONS

PLANNING PHASE

- SUGGEST PARTIAL PREPS/FASTENER LOOSENING/REMOVAL PRIOR TO CONTAINMENT ENTRY.
- CONSIDER ACCESSABILITY BUT KEEP IN MIND THAT ITEMS WHICH ARE INACCESSIBLE OR OBSTRUCTED BY INTERFERENCE MAY NOT HAVE BEEN ADEQUATELY INSPECTED BY THE LICENSEE.

- ESCORTS
  - KNOLEDGE OF PLANT
    - SYSTEMS
    - FUNCTION
    - LOCATION/ACCESS
  - KNOWLEDGE OF EQ
  - ELECTRICIAN(S)
  - HP TECHS

ASSISTANTS
- RECORDER

DONT TOUCH
- ENERGIZED

- TOOLS
  - CLIPBOARD
  - BAGS
  - FLASHLIGHT
  - SAFETY GEAR
  - INSPECTION MIRROR
  - MICRO CASSET
  - POLAROID
  - PENS/PAPER
  - RADCON / XEROX

- USE PLANT'S TOOLS

WALKDOWN

- AGREEMENT - ENSURE THAT A LICENSEE REP WITH SOME AUTHORITY OBSERVES WHAT YOU DO - SECURE AGREEMENT AS TO THE CONDITIONS OBSERVED - RECORD ACCURATELY DOCUMENT AGREEMENT - NAME/TITLE OF LIC. REP

- UNESCORTED ACCESS
  - NOT REQUIRED OR DESIRED FOR NRC HQ / CONTRACTORS

CONTRACTOR CONTROL

REGULATORY MATTERS - PRE BRIEF

ARGUMENTS - REFEREE

MASTER LIST VALIDATION

REVIEW OF PROCEDURES TO DEVELOP & MAINTAIN

" " (B)(2) ANALYSIS

" " DELETION JUSTIFICATIONS

GO OVER EOP'S WITH AN EQ EXPERT AND OPS EXPERT (MAY BE SAME PERSON)

SELECT ITEMS AT RANDOM

VERIFY ALL ON LIST OR JUSTIFYABLY REMOVED

- NOT IN HARSH ENV
- " " " FOR ACCIDENT ETC

* 0588 [illegible] TRICK

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

1 / Levis

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: Sandia Limitorque Lecture

6 pgs

DOCUMENT DATE: UNDATED

DOCUMENT RECEIVED FROM: W. LEVIS

TYPE OF DOCUMENT: Lecture Notes

RESPONSIVE TO ITEM NO: 39

EXEMPTION CLAIMED: NO

YES - ______________________

39-C

39

(W) proprietary Report

SANDIA LIMITORQUE LECTURE

I. EQ ISSUE

A. LOADING OF ACTUATORS DURING TESTING
1. ACTUATORS GENERALLY LOADED VIA THRUST TUBE.
2. RATED MOTOR TORQUE WAS NOT ACHIEVED.
3. RATED THRUST OUTPUTS WERE GENERALLY ACHIEVED.

B. DEGRADED VOLTAGE TESTING OF ACTUATORS ← we require this i.e. If not in Test Report Licensee must provide Analysis
1. NUREG 0588 CAT I AND II, 2.2.(10) REQUIRES TESTING AT EXTREMES IN VOLTAGE.
2. ONLY LIMITORQUE REPORT B0212 INCLUDED VOLTAGE VARIATIONS. (INSIDE PWR CONTAINMENT, RELIANCE F TYPE LR INSULATION).
3. FOR ACTUATORS NOT COVERED BY REPORT B0212, LICENSEE NEEDS TO SHOW ADEQUATE THRUST MARGIN EXISTS.

C. SIMILARITY ANALYSIS OF VARIOUS CLASS B
1. A SIMILARITY ANALYSIS REVIEWED AT LIMITORQUE WAS FOUND TO BE ACCEPTABLE FOR PEERLESS AC, PEERLESS DC, RELIANCE AC AND RELIANCE DC CLASS B MOTORS.

D. NYLON INSULATED WIRE JOINTS
1. NYLON INSULATED WIRE JOINTS USED IN SPLICING LEADS IN SOME DUAL VOLTAGE MOTORS ARE NOT QUALIFIED BY ANY LIMITORQUE REPORTS. NO TRACEABILITY OF THE TYPE OR MODEL OF WIRE JOINTS WHICH MAY HAVE USED WITH TESTED MOTORS WAS AVAILABLE AT LIMITORQUE.

E. LIMITORQUE TERMINAL BLOCK TEST B0119
1. MEGGER READINGS WERE TAKEN WITH MEGGER ON OHMS SCALE.
2. OUTPUT VOLTAGE OF MEGGER WAS 2.2 VOLTS.
3. SUITABILITY OF BLOCKS OTHER THAN MARATHON 300 FOR 480 VAC SERVICE IS NOT ENSURED.
4. TRANSCRIPTION ERROR FOUND IN DATA FOR CURTIS L BLOCKS.

F. T-DRAINS
1. T-DRAINS ARE REQUIRED ON ALL ACTUATORS THAT HAD T-DRAINS INSTALLED IN THEIR APPLICABLE EQ TEST.
2. ORIENTATION OF INSTALLED T-DRAINS IS IMPORTANT.
3. NO TEST EXISTS THAT QUALIFIES ACTUATORS WITHOUT T-DRAINS FOR INSIDE CONTAINMENT.

G. LUBRICANTS – Main gear housing + LS compartment
1. ONLY QUALIFIED LUBRICANTS ARE ACCEPTABLE.
2. FOR MAIN GEAR BOX, ACCEPTABLE LUBRICANTS ARE EXON NEBULA EP0 AND EP1. LUBRICANTS ARE LIGHT TAN IN COLOR.
3. SUN OIL COMPANY 50EP (XC-421-39) CAN BE USED FOR OUTSIDE CONTAINMENT. IT IS BLACK IN COLOR.

IN 79-03

3 on Lubricants

? 0 SQ IN 74-13

4. THE LIMIT SWITCH GEAR HOUSING SHOULD CONTAIN BEACON 325 (GREY/BEIGE) OR MOBIL 28 (RED/BROWN).

H. MOTOR BRAKES
  1. NONE TESTED FOR RADIATION.
  2. REPORT 600198 TESTED A DINGS BRAKE FOR INSIDE CONTAINMENT. TEST CONSISTED OF AGING 100 HOURS AT 180°C PLUS LOCA.
  3. REPORT F-C3271 TESTED A RELIANCE BRAKE. TEST CONSIDERED OF 212°F STEAM FOR 12 HOURS. NO AGING OR RADIATION.

II. IE NOTICES

A. 86-02 FAILURE OF ACTUATORS WITH MAGNESIUM ROTORS
  1. MOTORS WITH MAGNESIUM ROTORS FAILED A GE TEST FOR INSIDE CONTAINMENT BWR'S.
  2. FAILURE OCCURRED 7 DAYS AND 14 DAYS INTO THE LOCA.
  3. RELIANCE MOTORS OF FRAME SIZE 180 AND LARGER LIKELY CONTAIN MAGNESIUM MOTORS.
  4. LIMITORQUE OF SIZE SMB-0 OR LARGER MAY CONTAIN EFFECTED MOTORS. SMB-000 SMB-00 & smaller → SMB-1, 2, 3

B. 86-03 OPERATOR WIRING
  1. INTERNAL ACTUATOR WIRING IS NOT COVERED BY LIMITORQUE QUALIFICATION REPORTS.
  2. SEPARATE WIRE QUALIFICATION REPORT ARE REQUIRED.
  3. TI 2515/75 GIVES GUIDANCE FOR INSPECTING FOR PROPER WIRE.

C. 86-71 LIMIT SWITCHES, TORQUE SWITCHES, SPACE HEATERS
  1. FOR ACTUATORS QUALIFIED TO INSIDE CONTAINMENT REPORTS, LIMIT AND TORQUE SWITCHES SHOULD BE EITHER BROWN OR WHITE.
  2. FOR ACTUATOR QUALIFIED TO OUTSIDE CONTAINMENT REPORTS, SWITCHES CAN BE EITHER BROWN, WHITE, RED OR BLACK.
  3. ACTUATORS WERE NOT TESTED WITH SPACE HEATERS ENERGIZED. ADDITIONAL CALCULATIONS ARE REQUIRED FOR ENERGIZED SPACE HEATERS.

D. 87-08 DEGRADED MOTOR LEADS IN PEERLESS MOTORS
  1. PEERLESS MOTORS MANUFACTURED BETWEEN DECEMBER 1984 AND DECEMBER 1985, LIKELY CONTAIN INFERIOR UNQUALIFIED MOTOR LEADS.
  2. MOTORS WITH THESE LEADS MUST BE REPLACED.
  3. DATE CODES OF AFFECTED MOTORS GIVEN IN IE NOTICE

Has a list of plants that have these motors

Grease reliefs have to be on all actuators in containment

1. ENVIRONMENTAL QUALIFICATION ISSUE

A. LOADING OF ACTUATORS DURING TESTING

IT WAS DETERMINED THAT ACTUATOR LOADING DURING MOST OF THE LIMITORQUE ENVIRONMENTAL QUALIFICATION TESTS WAS BY MEANS OF A THRUST TUBE. THIS METHOD OF TESTING PROVIDES A LOAD ONLY AT THE END OF THE ACTUATOR CLOSING CYCLE. THE LOAD IS ACHIEVED BY DRIVING A STEM INTO A STATIONARY THRUST TUBE. THE TUBE STOPS THE STEM TRAVEL AND THE ACTUATOR IS LOADED UNTIL MOTOR CURRENT IS INTERRUPTED BY MEANS OF THE TORQUE SWITCH. THE LOAD ACHIEVED DURING TESTING IS THEREFORE DIRECTLY RELATED TO THE TORQUE SWITCH SETTING OF THE ACTUATOR. REVIEW OF LIMITORQUE TEST REPORT B0212 SHOWS THAT THE MOTOR INSTALLED IN THE TESTED ACTUATOR WAS RATED FOR 15 FOOT-LBS. USING AVERAGE TORQUE VALUES OBTAINED BEFORE THE TEST, A MOTOR TORQUE OUTPUT OF 14 FOOT-LBS. WAS CALCULATED TO HAVE BEEN ACHIEVED DURING THE EQ TEST OF THIS ACTUATOR. IN LIMITORQUE TEST B0009, A 25 FOOT-LB. RATED MOTOR WAS LOADED TO 13.4 FOOT-LBS. THE ABILITY OF THE LIMITORQUE MOTORS TO PUT OUT FULL RATED TORQUE WAS THEREFORE NOT PROVEN DURING THESE EQ TESTS. RATED THRUST OUTPUTS OF THE ACTUATORS WERE HOWEVER ACHIEVED DURING BOTH B0212 AND B0009 TESTS.

B. DEGRADED VOLTAGE TESTING OF ACTUATOR

IT WAS DETERMINED THAT LIMITORQUE REPORT B0212 IS THE ONLY REPORT THAT DESCRIBES TESTING OF AN ACTUATOR DURING DEGRADED VOLTAGE CONDITIONS. THE APPLIED VOLTAGE IN ALL OTHER TESTS WAS THE NOMINAL RATED MOTOR VOLTAGE. CALCULATIONS SHOW THAT AT A MINUS TEN PERCENT VOLTAGE CONDITION MOTOR TORQUE OUTPUT WILL DECREASE BY SOME 19%. LIMITORQUE REPORT B0212 IS FOR AN AC RELIANCE MOTOR. DC MOTOR PERFORMANCE UNDER DEGRADED VOLTAGE CONDITIONS WOULD BE CONSIDERABLY DIFFERENT.

THE STATEMENT CONCERNING DEGRADED VOLTAGE IN LIMITORQUE REPORT B0058 WAS DISCUSSED. IT WAS DETERMINED THAT THE MOTORS INSTALLED IN THE TESTED ACTUATORS WERE SIZED BASED UPON CALCULATIONS DONE USING NOMINAL MOTOR VOLTAGE. HAD DEGRADED VOLTAGE BEEN TAKEN INTO ACCOUNT LARGER MOTORS WOULD HAVE THEN BEEN REQUIRED ON SOME OF THE TESTED ACTUATORS. TO TAKE CREDIT FOR THE LIMITORQUE TESTS LICENSEES THEREFORE NEED TO SHOW THEIR ACTUATOR MOTORS WERE PROPERLY SIZED FOR THE APPLICABLE VOLTAGE CONDITIONS.

C. SIMILARITY ANALYSIS BETWEEN CLASS B AC PEERLESS, DC PEERLESS, DC RELIANCE, AND AC RELIANCE MOTORS

A SIMILARITY ANALYSIS CONTAINED IN A WYLE LETTER DATED AUGUST 10, 1982 TO STONE AND WEBSTER WAS REVIEWED. THIS LETTER CONTAINED A MATERIAL ANALYSIS OF THE MATERIALS USED IN CLASS B AC PEERLESS, AC RELIANCE, DC RELIANCE AND DC PEERLESS MOTORS.

THE ANALYSIS SHOWED THAT THE MATERIALS USED IN THE MANUFACTURE OF THE CLASS B DC PEERLESS, DC RELIANCE AND AC PEERLESS MOTORS WERE EQUAL TO OR BETTER THAN THOSE USED IN THE MANUFACTURE OF THE CLASS B AC RELIANCE MOTOR TESTED IN LIMITORQUE REPORT B0003. NO DEFICIENCIES IN THE WYLE MATERIAL ANALYSIS WERE NOTED.

D. QUALIFICATION OF NYLON INSULATION WIRE JOINTS

ACTUATORS EQUIPPED WITH DUAL VOLTAGE MOTORS HAVE BEEN FOUND TO CONTAIN NYLON INSULATION WIRE JOINTS. THESE WIRE JOINTS WERE USED AT LIMITORQUE TO MAKE CONNECTIONS ON DUAL VOLTAGE MOTORS. ACTUATORS TESTED IN LIMITORQUE REPORTS B0003, 600376A, AND 600198 CONTAINED DUAL VOLTAGE MOTORS THAT LIKELY CONTAINED SOME TYPE OF INSULATED WIRE JOINT. NO DOCUMENTATION AS TO THE EXACT TYPE OR AS TO THE JOINT MANUFACTURER EXISTS AT LIMITORQUE. ADDITIONALLY, NO CONFIGURATION CONTROL EXISTS THAT WOULD ENSURE THAT WIRE JOINTS ARE KEPT AWAY FROM CONDUCTING MATERIALS. THERE IS THEREFORE NO DOCUMENTATION THAT EXISTS

AT LIMITORQUE THAT WOULD SUPPORT ENVIRONMENTAL QUALIFICATION OF THESE NYLON INSULATION WIRE JOINTS.

E. LIMITORQUE TEST B0119

LIMITORQUE TEST B0119 DESCRIBES AT TEST IN WHICH A MARATHON 300 TYPE TYPE TERMINAL BOARD WAS USED TO POWER A MOTOR TO A LIMITORQUE ACTUATOR. THE TERMINAL BOARD WAS SUBJECTED TO AN INSIDE CONTAINMENT TYPE ENVIRONMENT AND WAS SHOWN TO ADEQUATELY TRANSMIT POWER TO THE SUBJECT MOTOR AT SELECTED PERIODS THROUGHOUT THE LOCA SIMULATED PORTION OF THE TESTING. RESISTANCE READINGS OF THE TERMINAL BOARD (TERMINAL TO TERMINAL AND TERMINAL TO GROUND) WERE THEN TAKEN BY DISCONNECTING THE MOTOR IMMEDIATELY AFTER ENERGIZATION.

THE LOWEST READING OBTAINED DURING THE TESTING FOR THE MARATHON 300 TERMINAL BOARD WAS 900 OHMS. SINCE THE MOTOR PERFORMED ADEQUATELY WITH THE 900 OHMS MEASURED INSULATION RESISTANCE THIS VALUE WAS SET AS THE ACCEPTANCE CRITERIA FOR REQUIRED MEASURE INSULATION RESISTANCE.

UPON REVIEW BY THE NRC INSPECTOR, IT WAS DETERMINED THAT THE MEASURED 900 OHMS INSULATION RESISTANCE WAS TAKEN USING A BIDDLE 21159 MEGGER. INSPECTION OF THIS MEGGER REVEALED THAT READINGS IN THE 900 OHMS RANGE COULD ONLY HAVE BEEN READ ON THE MEGGERS OHMS SCALE. THIS MEGGER HAS FOUR SCALES WITH FOUR ASSOCIATED OPEN CIRCUIT OUTPUT VOLTAGES. WITH THE OHMS SCALE USED IN OBTAINING THE 900 OHM READING, THE OUTPUT VOLTAGE APPLIED TO THE TERMINAL BOARD WOULD HAVE BEEN VERY LOW. FROM DISCUSSIONS WITH THE MANUFACTURER OF THE MEGGER, BIDDLE INSTRUMENTS, IT HAS BEEN DETERMINED THAT THE MEGGERS OUTPUT VOLTAGE UNDER THE ABOVE CONDITIONS WOULD HAVE BEEN APPROXIMATELY 2.2 VOLTS.

Although the other tested boards exhibited insulation resistance readings better than 900 ohms, these values were also obtained using the meggers ohms scale. Consequently, the ability of the other terminal boards tested in B0119 to adequately supply a 480 volt or 120 volt circuit has not been shown. Under the test conditions, all terminal boards would have indicated 0 ohms on the Biddle megger using the 500 volt or 250 volt scale.

Additionally, a data transcription error was discovered in the review. The values obtained at event 5 for the Curtis "L" type board were really 800 ohms, 700 ohms, and 1K, not 800K, 700K, and 1K as indicated in test report B0119. These values are therefore below the 900 ohm Limitorque acceptance criteria.

In conclusion, the ability of the Curtis "L," Marathon 1600, Buchanan 0222, Buchanan 0524 and GE-EB-5 type terminal boards to adequately supply 480 or 120 volt power to motor or control circuits has not been demonstrated by Limitorque Report B0119.

F. T-Drains

T-Drains are required on all actuators that had T-Drains installed in their applicable EQ test. The purpose of the T-Drain is to allow condensate to drain from the actuator. Internal parts susceptible to condensation failures would be the motor, limit switch, torque switch, terminal blocks and other electrical connections. If T-Drains are required their position should be such that they allow a condensate drainage path which would prevent collection of water around the susceptible components. For example, if an actuator is mounted with the motor higher than the limit switch comportment a T-Drain on the motor only would not be sufficient. Another unacceptable installation would be a T-Drain installed greater than 22° from the low point of a horizontally mounted motor.

Following is a tabulation taken from the NUGEQ report on Limitorque EQ Clarifications. The tabulation appears to be correct.

Report#	T-Drains Installed
600198	0
600376A	2
600470	2
B0009	1
B0003	0
F-C3271	0
B0027	2
B0212	2
B0119	2

NOTES

INSIDE CONTAINMENT REPORT 600198 APPLIES ONLY TO RELIANCE H TYPE MOTORS. ALSO, QUESTION EXISTS AS HOW WIRES ENTERING THE ACTUATOR WERE SEALED. NO RADIATION. MOTORS WERE AGED AT 180°C FOR 100 HOURS.

OUTSIDE CONTAINMENT REPORT B0003 APPLIES ONLY TO RELIANCE CLASS B MOTORS. AGED AT 105°F FOR 200 HOURS, RADIATION TO 20 MEGARADS.

OUTSIDE CONTAINMENT REPORT F-C3271 APPLIES ONLY TO RELIANCE CLASS B MOTORS. NO SPRAY, NO RADIATION, NO AGEING.

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS
IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

#2
LEVIS

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: EQ Inspection Program

28 pgs

DOCUMENT DATE: UNDATED

DOCUMENT RECEIVED FROM: W. LEVIS

TYPE OF DOCUMENT: INSPECTION PROGRAM GUIDANCE

RESPONSIVE TO ITEM NO: 39

EXEMPTION CLAIMED: NO

YES - ______

39-d

39-2

Dick Wilson

Mark

EQ INSPECTION PROGRAM

DESCRIBED IN SECY-85-220 (JUNE 18, 1985)

START 1ST ROUND INSPECTIONS OCTOBER 1984, COMPLETE OCTOBER 1987.

OBJECTIVES:

- REVIEW LICENSEES' IMPLEMENTATION OF PROGRAM FOR MEETING 10 CFR 50.49 REQUIREMENTS.
- REVIEW LICENSEES' IMPLEMENTATION OF SER CORRECTIVE ACTION COMMITMENTS. (FRC →)
- REVIEW LICENSEES' IMPLEMENATION OF PROGRAM FOR MAINTAINING QUALIFIED STATUS OF EQUIPMENT DURING THE LIFE OF THE PLANT.
- PERFORM PHYSICAL INSPECTION OF EQUIPMENT TO DETERMINE THAT THE INSTALLATIONS AGREE WITH SER COMMITMENTS/QUALIFICATION REQUIREMENTS.

PROGRAM TRANSFERRED TO REGIONS AFTER MODULE DEVELOPMENT AND COMPLETION OF PILOT PHASE.

NRR TO PROVIDE TECHNICAL SUPPORT (STAFF AND CONSULTANT) AND TO COORDINATE OVERALL SCHEDULING.

EQ INSPECTION PROGRAM

CURRENT STATUS OF FIRST ROUND INSPECTIONS

(AUGUST 1987)

	RI	RII*	RIII	RIV	RV	TOTAL
SITES COMPLETED	15	8	16	5	5	49
SITES REMAINING	10	9	4	3	1	27

*DOES NOT INCLUDE SPECIAL PROJECTS SITES.

Farley 2 ✓ Summer 1
NA 2 ✓ GG 1
Vogtle 2 Oconee 3
Catawba 2
Harris 1

WB
BFN
BNP

SNL-NRC/EQ/UP-2/10

GENERIC LETTER 85-15 (AUGUST 6, 1985)

PRO DES FOR CIVIL PENALTIES OF $5000 PER ITEM PER DAY WHICH MAY BE RETROACTIVELY IMPOSED:

> FOR NONCOMPLIANCE IDENTIFIED AFTER NOVEMBER 30, 1985, FOR EACH DAY A LICENSEE CLEARLY KNEW OR SHOULD HAVE KNOWN THAT EQUIPMENT QUALIFICATION WAS INCOMPLETE.

ESTABLISHED 3 MITIGATION FACTORS:

1. PROMPT IDENTIFICATION AND REPORTING.
2. BEST EFFORTS TO COMPLETE ENVIRONMENTAL QUALIFICATION BEFORE DEADLINE.
3. FULL COMPLIANCE WITHIN REASONABLE TIME.

Completed
CR
St Lucie
T.P
Hatch
Surry
McGuire
Robinson
Brunswick

GENERIC LETTER 85-15 (AUGUST 6, 1985)

DEFINES "UNQUALIFIED EQUIPMENT:"

"EQUIPMENT FOR WHICH THERE IS NOT ADEQUATE DOCUMENTATION TO ESTABLISH THAT THE EQUIPMENT WILL PERFORM ITS INTENDED FUNCTIONS IN THE RELEVANT ENVIRONMENT."

DEFINES "ITEM:"

"SPECIFIC TYPE OF ELECTRICAL EQUIPMENT, DESIGNATED BY MANUFACTURER AND MODEL WHICH IS REPRESENTATIVE OF ALL IDENTICAL EQUIPMENT IN A PLANT AREA EXPOSED TO THE SAME ENVIRONMENTAL SERVICE CONDITIONS."

GENERIC LETTER 86-15 (SEPTEMBER 22, 1986)

REQUIRES LICENSEES TO MAKE PROMPT DETERMINATION OF OPERABILITY WHEN UNQUALIFIED EQUIPMENT IS IDENTIFIED...

AND...

TO TAKE IMMEDIATE STEPS TO ESTABLISH A PLAN WITH A REASONABLE SCHEDULE TO CORRECT THE DEFICIENCY.

WRITTEN JUSTIFICATION FOR CONTINUED OPERATION (JCO) IS REQUIRED, BUT DOES NOT HAVE TO BE REVIEWED AND APPROVED BY NRC.

GENERIC LETTER 86-15 (SEPTEMBER 22, 198.)

REQUIRES LICENSEES TO MAKE PROMPT DETERMINATION OF OPERABILITY WHEN UNQUALIFIED EQUIPMENT IS IDENTIFIED...

AND...

TO TAKE IMMEDIATE STEPS TO ESTABLISH A PLAN WITH A REASONABLE SCHEDULE TO CORRECT THE DEFICIENCY.

WRITTEN JUSTIFICATION FOR CONTINUED OPERATION (JCO) IS REQUIRED, BUT DOES NOT HAVE TO BE REVIEWED AND APPROVED BY NRC.

DEFINES "OPERABLE:"

- [illegible]ASONABLE ASSURANCE THAT THE EQUIPMENT WILL PERFORM SAFETY FUNCTION(S) PRIOR TO FAILURE...

AND...

- SUBSEQUENT FAILURE WILL NEITHER DEGRADE ANY OTHER SAFETY FUNCTION NOR MISLEAD THE OPERATOR.

FOR EQUIPMENT DEEMED INOPERABLE:

- INVOKES TECH SPECS FOR EQUIPMENT COVERED BY THEM.
- ALLOWS FOR OPERATION UNDER CERTAIN CONDITIONS IF INOPERABLE EQUIPMENT IS NOT UNDER TECH SPECS.

GENERIC LETTER 86-15 (SEPTEMBER 22, 1986)

TRANSMITS ENFORCEMENT GUIDANCE RELATED TO GL 85-15.

- APPLICATION OF "CLEARLY KNEW OR SHOULD HAVE KNOWN" TEST.
- TIME PERIOD FOR CIVIL PENALTY
  $500,000 PER ITEM CAP
- APPLICATION OF THE MITIGATION FACTORS
  $50,000 PER ITEM MINIMUM.
- OTHER ENFORCEMENT REGARDING VIOLATIONS OF EQ REQUIREMENTS IDENTIFIED AFTER NOVEMBER 30, 1985.
- IF VIOLATION EXISTED BEFORE DEADLINE, APPLY "CLEARLY KNEW OR SHOULD HAVE KNOWN" TEST.
- IF VIOLATION DOES NOT RELATE TO ACTION OR LACK OF ACTION BEFORE DEADLINE, USE NORMAL ENFORCEMENT.

SECY 87-32 (FEBRUARY 6, 1987)

PROPOSES THAT NO ENFORCEMENT ACTION BE TAKEN FOR CERTAIN VIOLATIONS I.E., UNQUALIFIED VALVE MOTOR OPERATOR INTERNAL WIRING.

COMMITS STAFF TO REVIEW LICENSEE SELF-IDENTIFIED EQ VIOLATIONS IN ACCORDANCE WITH ENFORCEMENT CRITERIA FOR EQ VIOLATIONS AND TAKE ENFORCEMENT ACTION AS APPROPRIATE.

EGM 87-02 (APRIL 10, 1987)

PROVIDES FURTHER GUIDANCE IN THE APPLICATION OF EQ ENFORCEMENT POLICY.

ESTABLISHES THRESHOLD FOR ESCALATED ENFORCEMENT:

THE QUALIFICATION DEFICIENCY IS NOT CONSIDERED SUFFICIENTLY SIGNIFICANT FOR ASSESSMENT OF CIVIL PENALTIES IF...

- SUFFICIENT DATA EXISTS OR IS DEVELOPED DURING THE INSPECTION TO DEMONSTRATE QUALIFICATION OF THE EQUIPMENT...

OR...

- BASED ON OTHER INFORMATION AVAILABLE TO THE INSPECTOR, THE SPECIFIC EQUIPMENT IS QUALIFIABLE FOR THE APPLICATION IN QUESTION.

EQ DEFICIENCIES

SEVERITY CLASSIFICATIONS

POTENTIALLY ESCALATED

A. SIGNIFICANT AUDITABILITY/PROGRAMMATIC PROBLEMS (GENERIC)

B. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION - EQUIPMENT QUALIFICATION STATUS INDETERMINATE.

SEVERITY LEVEL IV/V

C. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION, BUT EQUIPMENT CONSIDERED QUALIFIABLE.

D. SIGNIFICANT QUALIFICATION DEFICIENCIES CORRECTED DURING INSPECTION.

E. ISOLATED AUDITABILITY/PROGRAMMATIC PROBLEMS.

OPEN ITEMS

F. MINOR FILE DEFICIENCIES, WALKDOWN OBSERVATIONS.

EQ DEFICIENCIES

TYPE CLASSIFICATION

A. EQUIPMENT NOT QUALIFIED/NOT ON EQ LIST

B. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE NOT ESTABLISHED IN QUALIFICATION FILE.

C. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE INVALIDATED BY IMPROPER INSTALLATION/MAINTENANCE.

D. QUALIFICATION TEST PARAMETERS DID NOT ENVELOPE PLANT ENVIRONMENT.

E. PLANT SPECIFIC PERFORMANCE REQUIREMENTS FOR EQUIPMENT NOT ESTABLISHED/EQUIPMENT PERFORMANCE NOT DEMONSTRATED.

F. REPLACEMENT EQUIPMENT NOT UPGRADED TO CURRENT REQUIREMENTS. (WITH NO "SOUND REASONS TO THE CONTRARY")

G. SIGNIFICANT ERRORS IN QUALIFICATION ANALYSIS (QUALIFIED LIFE CALCULATIONS IMPROPERLY PERFORMED, TEST ANOMALIES NOT RESOLVED, ETC.).

EQ DEFICIENCIES

TYPE CLASSIFICATION

A. EQUIPMENT NOT QUALIFIED/NOT ON EQ LIST (§50.49(F),(D),(J))

B. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE NOT ESTABLISHED IN QUALIFICATION FILE. (§50.49(F)(2),(3)), (DOR-5.2.2), (0588 I & II - 5(2))

C. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE INVALIDATED BY IMPROPER INSTALLATION/MAINTENANCE.(SAME)

D. QUALIFICATION TEST PARAMETERS DID NOT ENVELOPE PLANT ENVIRONMENT. (§50.49(E)), (DOR-5.2.1), (0588 I & II - 2.2(4))

E. PLANT SPECIFIC PERFORMANCE REQUIREMENTS FOR EQUIPMENT NOT ESTABLISHED/EQUIPMENT PERFORMANCE NOT DEMONSTRATED. (§50.49(J)(2)),(DOR-5.2.5),(0588/I&II-2.1(3),2.2(7),(9),5(1))

F. REPLACEMENT EQUIPMENT* NOT UPGRADED TO CURRENT REQUIREMENTS (WITH NO "SOUND REASONS TO THE CONTRARY") (§50.49(L)/RG 1.89, REV 1).

G. SIGNIFICANT ERRORS IN QUALIFICATION ANALYSIS (QUALIFIED LIFE CALCULATIONS IMPROPERLY PERFORMED, TEST ANOMALIES NOT RESOLVED, ETC.). (§50.49(F),(J)), (DOR-5.1/5.3/VARIOUS), (0588 I & II - 2.1(4),2.4,5(1))

*NOTE: EQUIPMENT <u>PURCHASED</u> AFTER 2/22/83 (10CFR50.49 EFF. DATE), 10CFR50.49. §50.49(K) ALLOWS FOR NOT REQUALIFYING EQUIPMENT QUALIFIED UNDER DOR GUIDELINES (O.L. ≤ 5/23/80) OR NUREG-0588 (O.L. > 5/23/80) - CAT I (C.P. > 7/1/74) OR CAT II (C.P. < 7/1/74). SOME DOR & CAT II PLANTS COMMITTED TO NUREG-0588(I) FOR NUREG-0737 AND/OR RG 1.97 EQUIPMENT.

CRITERIA - P1

- APPENDIX A - GDC 1, 2, 4, 23
- APPENDIX B - CRITERIA 3, 11
- 10 CFR 50.55a(h) - IEEE 279-1971
- IEEE 323-1971 (SOME POST-1971 OL)
- R.G. 1.89 AND 323-74 (CP SER AFTER 7/1/74)
- DAUGHTER STANDARDS
- STANDARD REVIEW PLAN SECTION 3.11
- SEP TOPIC III-12, 12/77
- UCS PETITIONS 11/4/77, 5/2/78
- DOR GUIDELINES, NOV 79
- NUREG 0588 (FOR COMMENT), DEC 79 CAT I AND II, CP SER 7/1/74
- IEB 79-01B, 1/14/80 (PREDEC. AND SUPPL.)
- SEP PLANT MEETING, 2/21/80 (IP, ZION)
- CLI-80-21, 5/23/80 - DEADLINES, RULEMAKING
- 10 CFR 50.49 (PUB. 1/21/83, EFF. 2/23/83)
- R.G. 1.89 REV. 1

RCW-1A

W-1

CONDUCT OF INSPECTIONS

- INSPECTION MODULE
- REFERENCE INFORMATION
- PREPARATION FOR INSPECTION
  - PRE-INSPECTION DOCUMENT REVIEW
  - SAMPLE SELECTION
- EQUIPMENT FILE REVIEW
- PROGRAM/PROCEDURE REVIEW
- MASTER LIST
- WALK-DOWN
- FEEDBACK TO LICENSEE
- EXIT MEETING

INSPECTION MODULES

- TI 2515/76 EQ PROGRAM
- TI 2515/75 LIMITORQUE WIRING
- TI 2500/17 RAYCHEM SPLICES
- TI 2515/87 REG. GUIDE 1.97

Find Licensee Status & SER @ have been issued by NRR

SNL-NRC/EQ/RW-09/12

W-3

PRE-INSPECTION ACTIVITIES

- HQ COORDINATE SCHEDULES
- REGION CONTACT LICENSEE
  - ESTABLISH DATES
  - REQUEST ADVANCE INFORMATION (SEE TI §04, ADD QC REPORTS)
  - DETERMINE FILE LOCATION AND HQ CONTACT
- HQ ISSUE LETTER TO LICENSEE
- TEAM LEADER PHONE LICENSEE
  - SCOPE
  - LOGISTICS
  - WALKDOWN PREP
  - LICENSEE ENTRANCE MEETING PRESENTATION
    - ORGANIZATION
    - PROCEDURES
    - FILE ARRANGEMENT
- REGION & TEAM LEADER CALL RESIDENT
- TEAM LEADER COORDINATE WITH NRR PM

Conax pigtails at EPA

does he know of any concerns at the site

moisture intrusion (seals at xmtrs, motors)

splices

TB

connectors

cable identification during walkdown for traceability

cable identification exercise

loop error calculation splices, connectors T/B, cable IR

REV-2.

W-4

LICENSEE PROGRAM REVIEW

- CORPORATE POLICY STATEMENT — everybody should pay close attention to EQ
- IDENTIFICATION OF RESPONSIBLE ORGANIZATION
- DEFINITION OF ORGANIZATIONAL INTERFACES

use ... QA Background or Class 1E Equip

SNL-NRC/EQ/RW-01/12

W-5

MASTERLIST-10 CFR 50.49 LIST

- PROCEDURES FOR DEVELOPING LIST ✓
- PROCEDURES TO CONTROL LIST ✓
- REVIEW OF LIST
  - P&IDs
  - EOPs
  - ENVIRONMENTAL DRAWINGS
  - SYSTEM APPROACH

Sampling / spot check – used to check list are licensee's EOP

Some sort of methodology to creating the master list

SNL-NRC/EQ/RW-02/12

W-6

MAINTENANCE-PRESERVATION OF QUALIFIED STATUS

- EQ REQUIREMENTS
    - REQUIRED
    - RECOMMENDED
    - NORMAL

- PROCEDURES
    - EXISTING
    - EQ SPECIFIC
    - ROUTINE/NONROUTINE
    - IN-KIND REPLACEMENTS
    - MODIFICATIONS
    - IE INs/BULLETINS
    - TREND ANALYSIS
    - PROCUREMENTS

- STORAGE

PROCUREMENT

- FEBRUARY 22, 1983
- EXCEPTIONS TO UPGRADING
- NEW EQUIPMENT
- REPLACEMENT EQUIPMENT
- REPLACEMENT PARTS
- EQ REQUIREMENTS IN PURCHASE ORDERS
- COMPLIANCE WITH PURCHASE ORDER REQUIREMENTS

Procedure for substitution of parts not identical unless they have cert from vendor that it is the same - Also need to insure that vendor has QA program & has been audit by Licensee

Licensee can also buy commercial grade but they have to have a program to up grade + paper

SNL-NRC/EQ/RW-05/12

W-9

MODIFICATIONS/DESIGN CHANGES

- PROCEDURES ADDRESS EQ CONSIDERATIONS
  - EQUIPMENT
  - ENVIRONMENTAL

REGION SCOPE, EQ INSPECTION

	TYPICAL SPLIT BETWEEN 2 MEN	
OVERALL EQ PROGRAM	X	
MASTER LIST COMPLETENESS AND UPDATING		X
MAINTENANCE (CAN SPLIT I&C VS ELECTRICAL)		X
TRAINING		X
QA/QC	X	
PROCUREMENT & SPARE PARTS	X	
IEB/IN PROCESSING FOR EQ	X	
CABLE IDENTIFICATION SYSTEM		X
FILES (ONE EACH)	X	X

SAMPLE SELECTION - P2

- QUESTION ITEMS REMOVED FROM M/L
- QUESTION SURPRISING OMISSIONS FROM M/L ← splice, TB, cable entrance seals, cables Connectors
- REVIEWER ASSIGNMENTS -
  - QUANTITY
  - SPECIALTY
  - PRIORITY
  - SCHEDULE - GRAVITY VS. WALKDOWN
- NTOL DOCUMENTATION DIFFERENT — SER 3.11

EG&G Limitorque

Sandia Files

Let Reviewers know ahead of time of what they are going to review

Also if you want specific items to be looked at

Rank items in priorities

RCW-3B

W-15

WALKDOWN INSPECTION

- USUALLY WEDNESDAY AFTERNOON
- FULLY ESCORTED, MINIMAL H/P & SECURITY
- FOLLOW INSTRUCTIONS
- PREPARE IN ADVANCE -
    - CHECKLIST
    - SCEW SHEETS
    - MAINTENANCE INSTRUCTIONS
    - MAINTENANCE RECORDS

— Take with you to verify S/N, Model Numbers then if paper got containing had it can be discarded + you then know that you verified

Besure escort understands what your concerns are with a piece of equip at the time you are at the equip.

Possibly use tape recorders

RCW-5

W-17

TYPICAL PROBLEM AREAS

- PLANT PERFORMANCE SPECIFICATIONS

  TERMINAL BLOCKS (VARIOUS APPLICATIONS)

  CABLE (DITTO)

  PRESSURE, ETC. SWITCH ACCURACY

- SELF HEATING (SOLENOID VALVES)

- SIMILARITY (DOR G/L)

- CALCULATED LIFE (DOR G/L)

  COMPLETE MATERIALS LIST

  INSTALLATION DATE

- REPLACEMENT EQUIPMENT UPGRADED

RCW-7

W-19

CONTAINMENT ELECTRICAL
PENETRATION ASSEMBLIES

* FORT CALHOUN - FIRST EQ LEVEL III NOV — Level III → DG OBrien
* DRESDEN - UNQUALIFIED AMP SPLICES GE - Escalated enforce unqualified Amp Splice
* SAN ONOFRE 1 - REPLACEMENT EQUIPMENT PROBLEMS -- Conax

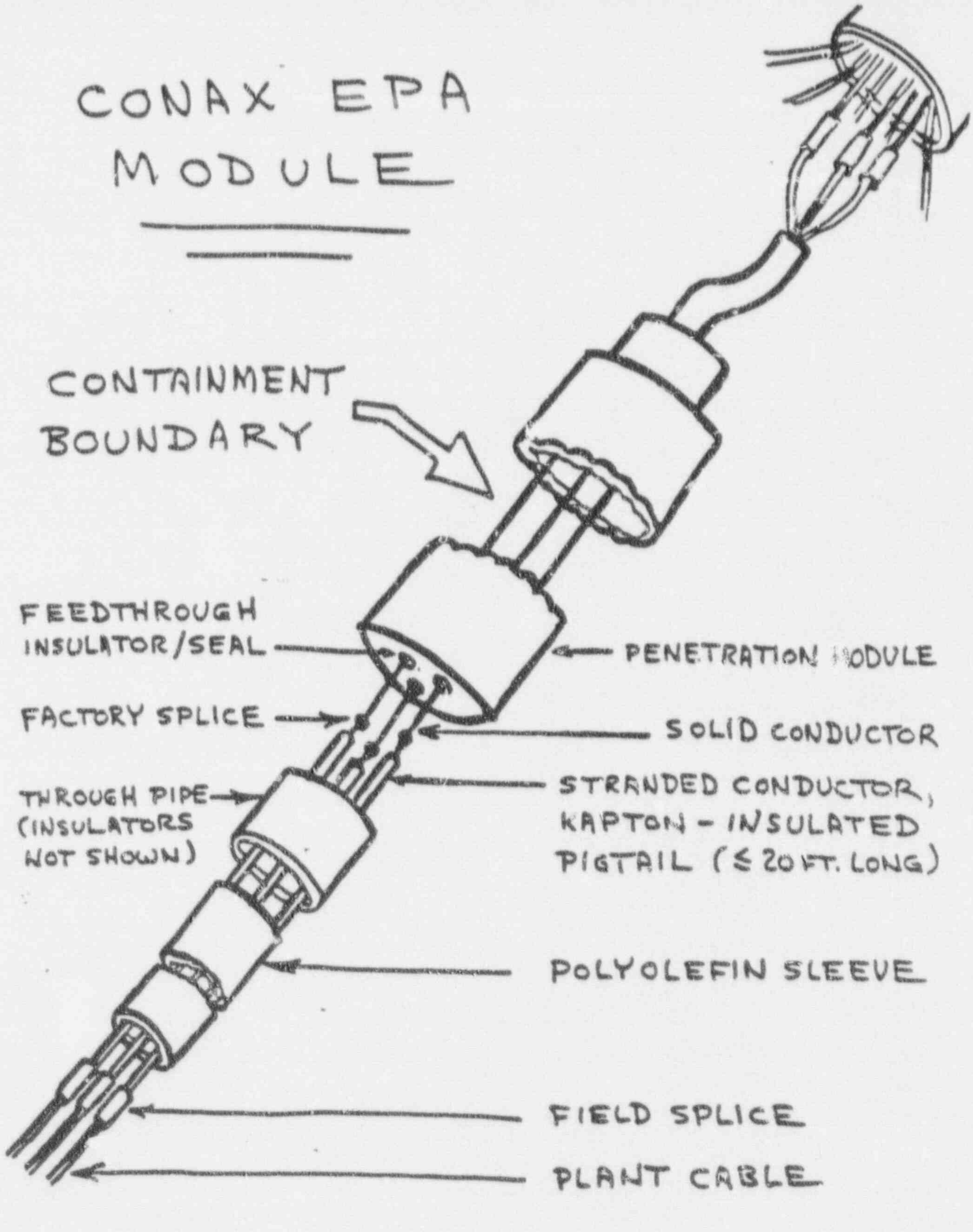
  H.B. ROBINSON - TWO PLANT SHUTDOWNS Crouse-Hinds

* IEB 82-04 - BUNKER RAMO-SPLICES, INSULATION, AND EPOXY

↗ Bulletin

SNL-NRC/EQ/RW-11/12

W-21


CONAX EPA
MODULE
CONTAINMENT
BOUNDARY
FEEDTHROUGH
INSULATOR/SEAL
PENETRATION MODULE
FACTORY SPLICE
SOLID CONDUCTOR
THROUGH PIPE
(INSULATORS
NOT SHOWN)
STRANDED CONDUCTOR,
KAPTON - INSULATED
PIGTAIL (≤ 20 FT. LONG)
POLYOLEFIN SLEEVE
FIELD SPLICE
PLANT CABLE

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

#3/ LEVIS

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: Qualified Equipment - Specific Examples

48 pgs

DOCUMENT DATE: UNDATED

DOCUMENT RECEIVED FROM: W. LEVIS

TYPE OF DOCUMENT: TECHNICAL INFO RE EQUIPMENT

RESPONSIVE TO ITEM NO: 39

EXEMPTION CLAIMED: NO

YES - ______________________

39-e

39-2

QUALIFIED EQUIPMENT - SPECIFIC EXAMPLES

- TERMINAL BLOCKS
- LIMIT SWITCHES
- SOLENOID OPERATED VALVES
- TRANSMITTERS
- SPLICES AND TERMINATIONS

TYPES

USES

MANUFACTURERS

QUALIFIED MODELS

INSTALLATION

REPORTS

PERFORMANCE REQUIREMENTS

FAILURE MODES { ACCIDENTS
TYPE OF ELECTRICAL FAULTS

OPERABILITY EVALUATIONS

REPORTS

ANOMALIES/PROBLEMS

TEST REPORTS

10CFR21

50.72 IM. NOTIF. NRC PT 21/50.55(e) D.B.

50.73 LER

50.55(e)

IE B's

IE IN's

VENDOR NOTIFICATIONS

e.g. GE's SIL's, SAL's, PRC's, GERMAIN TO SAFETY

ROCKBESTOS LETTER ON ISOMEDIX

TERMINAL BLOCKS

PRINCIPAL MANUFACTURERS OF QUALIFIED BLOCKS

- GE — EB-5,25
- WESTINGHOUSE
- BUCHANAN — 224, 524
- CURTIS — Type L
- MARATHON — 300, 1500, 1600, 1600NUC, 6000
- KULKA
- WEIDMULLER
- STATES

CONSTRUCTION, MATERIALS (Size, Shape, SOLID/SEGMENTED)

INSTALLATION (ENCLOSURES, ORIENTATION, MOUNTING)

PROBLEMS

FAILURE MODES

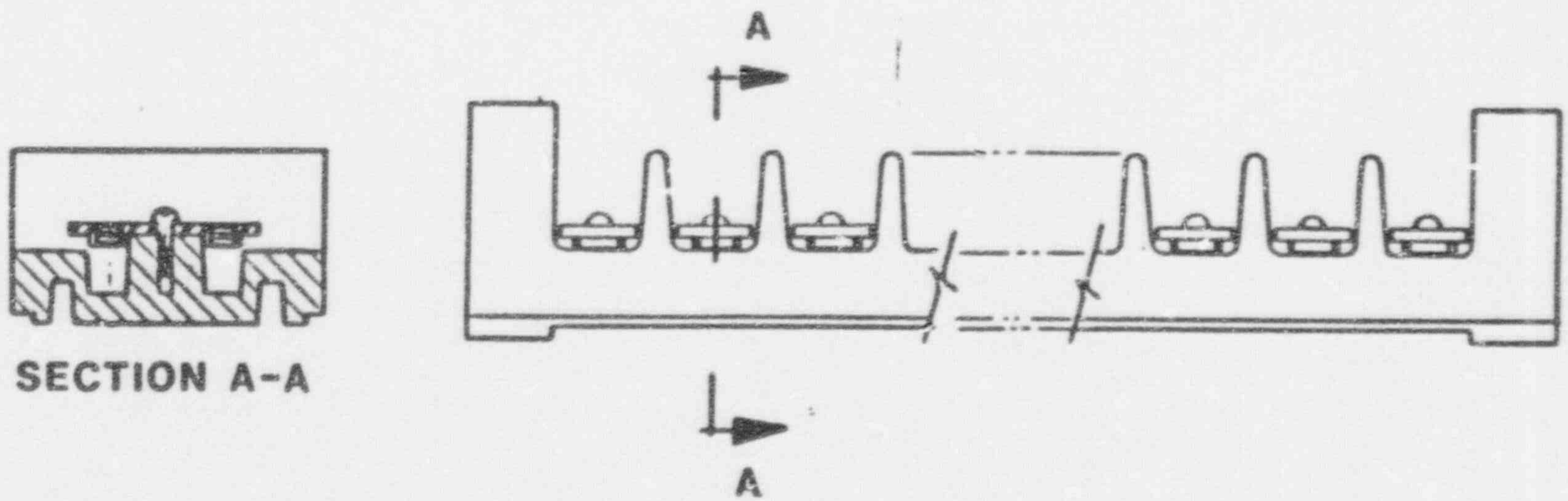


Figure 2-1: Typical Configuration for a One-Piece Terminal Block

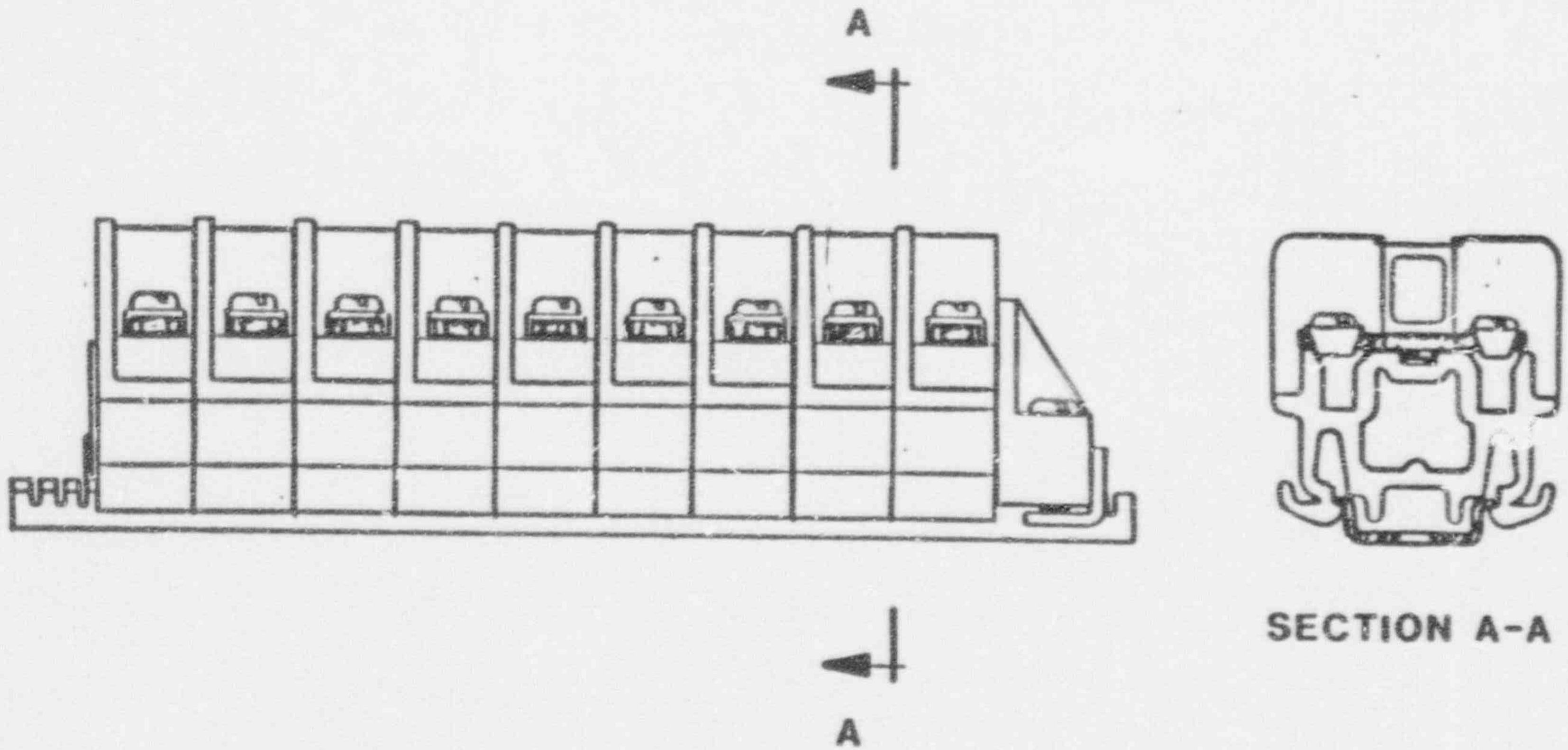


Figure 2-2: Typical Configuration for a Sectional Te.minal Block

TERMINAL BLOCKS

TYPES

SOLID OR SECTIONAL (SEGMENTED)

USES	SERVICE	VOLTAGE
POWER	MOVs	480/240VAC
CONTROL	SOVs, MOVs, DPISs, LSs, PSs, TSs	120VAC/125VDC
INSTRUMENTS	PT,PT,LT,TEs	<50VDC

HOW USED - CONNECTING DEVICE LEADS TO FIELD-RUN CABLE - TO OTHER CKTs OR EPAs

MANUFACTURERS

INSTALLATION
- ENCLOSURES (e.g., NEMA-4)
- ORIENTATION
- MOUNTING

ADVANTAGES/DISADVANTAGES

TERMINAL BLOCKS

REPORTS

INDIVIDUAL MANUFACTURERS SPONSORED

LICENSEE SPONSORED

__ JOINT TESTS - LIMITORQUE B0119

SANDIA REPORTS (CRAFT)
INDUSTRY ASSESSMENT - NRUEG/CR-3691
SANDIA SCREENING TESTS - NUREG/CR-3418

PERFORMANCE REQUIREMENTS/ACCEPTANCE CRITERIA

FAILURE MODES

OPERABILITY EVALUATIONS (GL 86-15)
FUNCTION PRIOR TO FAILURE
NO SAFETY DEGRADATION FROM FAILURE
OPERATOR NOT MISLEAD

ANOMALIES/PROBLEMS

IE~~C~~IN's

84-73 (IN LIMITORQUES) SMC-04: BEAR GOOD

82-03 GE & STATES

83-72 BUCHANAN

84-47 KULKA

~~84-78~~

Table 3-1
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohmmeter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
Philadelphia Electric/ FRC*	Buchanan 2B104 2B108	 2 4	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$<5\times10^4$ at 50 Vdc	10^2 to 10^{12}	One block removed from test at 4.9 days. Others removed at various times.	14 d	14 Phase A
Philadelphia Electric/ FRC*	Buchanan 2B108 Marathon 1608	 3 2	Ability to carry specified current at specified voltage.	150 Vac 12.5 A	$<5\times10^5$ at 50 Vdc	$<5\times10^4$ at 50 Vdc to $<5\times10^5$ at 50 Vdc	One TB removed from from test after 5.1 hours.	7d	14 Phase B
Generic/ FRC*	Buchanan MQB106 MQB112 MQB106S MQB112S MQO Series	 1 1 1 1 1	Maintain potential of 120 V and current of 25 A.	120 Vac 25 A	$<5\times10^4$ at 10 V to 2×10^{12} at 500 V	Post-test hipot test	During LOCA, leakage currents were < 200 mA to < 5 mA for all terminal blocks together.	7 d	15
Generic/ Wyle (Huntsville)	Marathon 1600 NUC 1500 NUC 342 NUC	 6 6 6	Leakage currents less than 12 A, or 18 A, or 24 A. Monitored by fuse.	132 Vac, 33 A 264 Vac, 33 A 528 Vac, 33 A	None	$<5\times10^5$ for all 528 V boxes	Blew 25 A fuse on 528 Vac specimens. Removed from test. Blew 18 A fuse on 264 Vac specimens. Replaced fuse and continued.	30 d	16
Generic/ FRC*	Weidmuller SAK Types	5	Maintain 600 Vac and 20 A with leakage current less than 1 A. Monitored by fuse.	600 Vac 20 A	None	2.4×10^7 to 3.5×10^8 at 500 Vdc	Voltage reduced to 150 V when spray introduced to maintain leakage current less than 1 A.	29 hr	17

*FRC = Franklin Research Center

Table 3-1 (continued)
Comparison of Some Industry LOCA Simulations for Terminal Block Qualification

Utility/ Test Lab	TB ID	No. Tested	Acceptance Criteria	Power	Megohmmeter Measurements (ohms) (500 Vdc unless noted) During LOCA	Post-LOCA	Special Notes	Length of LOCA Exposure	Ref.
WPPSS/Wyle (Norco)	Weidmuller SAK Types (same TBs as tested by Weidmuller, Ref. 3)	5	1 A Leakage current monitored by fuse and discrete time monitoring of leakage currents.	600 Vac 20 A	None	1.2×10^{5} to 5.0×10^{10}	Measured leakage current during test. Test was only a post-test LOCA soak. 230°F and 20 psig, 100% relative humidity. No steam.	32 d	18
Generic/ Wyle (Norco)	Phonix SSK Series Ceramic EEK Series Ceramic SSK Series Melamine E Series Polyester (3 Types)	30 units exposed to LOCA	None specified	420 Vac 20 A 48 Vdc 24 Vdc	None Reported		2 superheated steam periods. No leakage current measurements of DC circuits. < 40 mA to > 709 mA current observed in 420 Vac case	24 hr	19
Commonwealth Edison/Wyle (Huntsville)	Marathon Series 6000 Series 1600	2 2	Leakage current less than 10 A. Monitored by fuse.	175 Vac 15 A	None	$< 1.6 \times 10^{6}$** to 2.2×10^{12} at 500 Vac **Off scale low. Measurement with Digitial Multimeter read 3.6 ohms	Some periods of superheat in accident exposure. One block exceeded 10 A leakage current--shorted to ground.	36.9 hr	20
Generic/ Westinghouse	Curtis BT Cinch Jones 541 Westinghouse 542-247 Marathon 1500		None Specified	600 Vac	8×10^{3} to 5×10^{5}	2×10^{10} to 2.3×10^{11}	Leakage currents not monitored during test with blocks powered.	≈ 21 hr	21

*FRC = Franklin Research Center

Table 7-1

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/Symptom	Comments
Gross Electrical Breakdown (e.g., low resistance path terminal-to-terminal or terminal-to-base plate)	Low Voltage Surface Breakdown*	Environmental Conditions High Temperature Humidity/Moisture Contaminants	Voltage Exposure Time Insulation Type	Loss of Circuit Operability	Temporary
		Volatile/Soluble Surface Contamination	Contaminant Deposition Rate		Temporary
		Radiation	Aging Normal Accelerated		
		High Leakage Currents and Surface Tracking			
		Non-Volatile Surface Contamination	Corrosion Products Conductive Residue		Permanent
	Conducting Path	Thermal and/or Pyrolytic Decomposition of Insulation	High Temperature Exposure to Burning Environment	Loss of Circuit Operability	Permanent
		Structural Failure	Excessive Temperature Excessive Thermal Shock Vibration	Cracking of Insulation	Permanent

* High voltage breakdown not included due to lack of HV circuits in nuclear applications

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Gross Electrical Breakdown (continued)	Conducting Path (continued)	Structural Failure (continued)	Improper Maintenance		
			Improper Installation		
			Aging		
	Bulk Insulation Breakdown	Radiation			
		Moisture Absorption Cracking	Moisture Absorption	Splitting of insulation and formation of conducting paths	
Leakage Currents	Surface Conduction	Surface Contamination	Installation Practices	Low Frequency Line Noise	Some leakage will always occur. The question is a matter of degree. Leakage of a few milliamperes may be detrital to an instrumentation circuit, but have no effect on a power circuit.
		Environmental Conditions (e.g., High Temperature Humidity/Moisture, Contaminants)	Maintenance Practices	Circuit Crosstalk	
			Voltage Level	Excessive Power Drain	
			Aging	Biased Readings on Instrument Outputs	
		Radiation	Access for beta-emitting isotopes	Gross Breakdown	

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Leakage Currents (continued)	Surface Conduction (continued)	Structural Failure	Excessive Temperature	Cracking of Insulation	
			Excessive Thermal Shock		
			Vibration		
			Improper Maintenance		
			Improper Installation		
Open Circuit	Separation of Conductor	Loose Terminal Screws		Loss of Circuit Operability	
		Contact Corrosion	Chemical Reagents		
			Moisture/ Humidity		
		Structural Failure	Vibration	Cracking of Conductor	
			Thermal Shock		
			Improper Maintenance		
			Improper Installation		
			Differential Expansion		

Table 7-1 (continued)

Summary of Failure Modes for Terminal Blocks

Failure Mode	Mechanism	Potential Causes	Contributing Factors	Effect/ Symptom	Comments
Open Circuit (continued)	Separation of conductor (continued)	High Leakage Currents			
		Failure to Reconnect Terminals	Careless Maintenance Procedures		
			Lack of Quality Assurance		

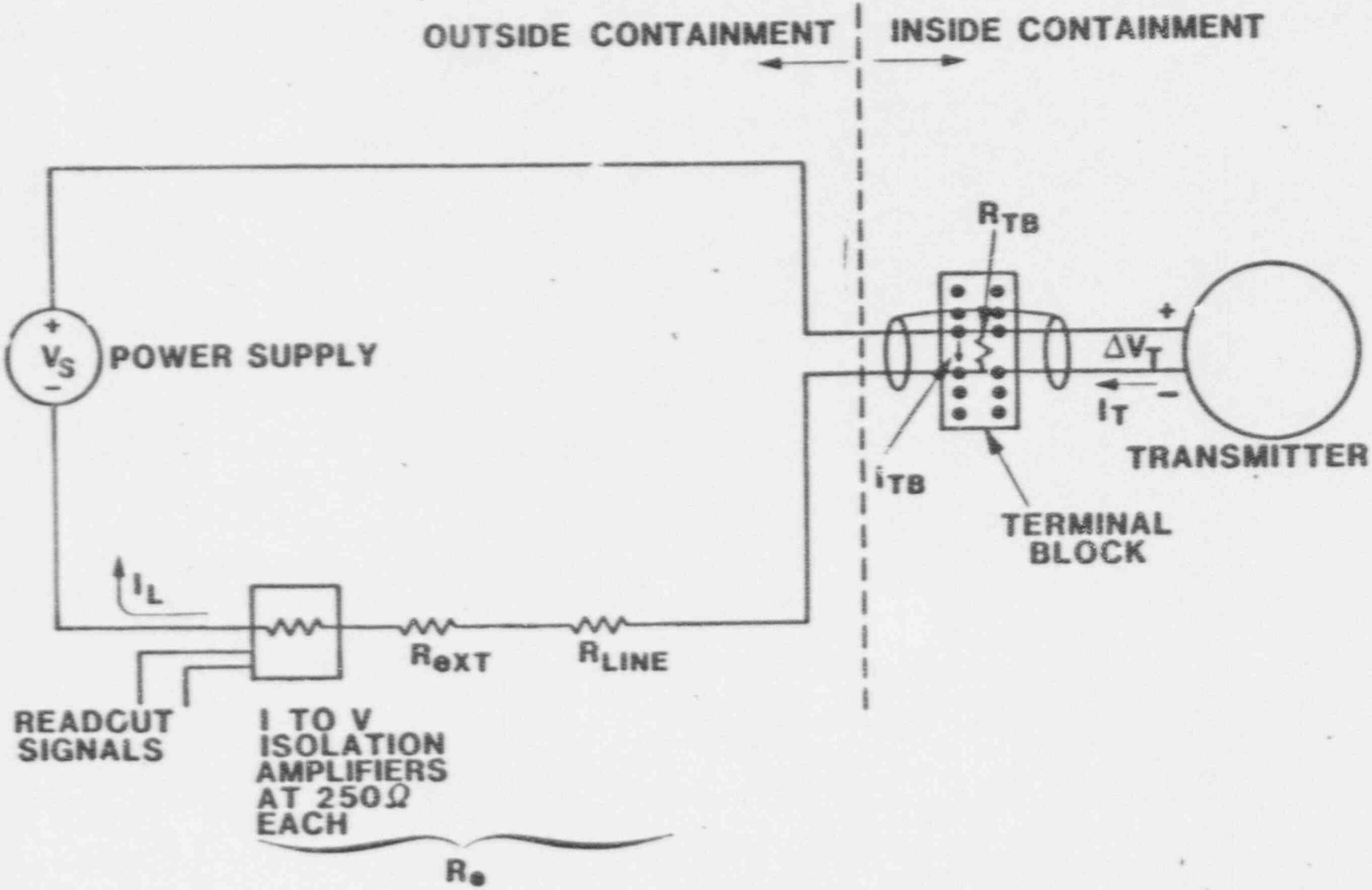


Figure 8-1: Simplified Schematic of a Typical Transmitter Circuit in a Nuclear Power Plant

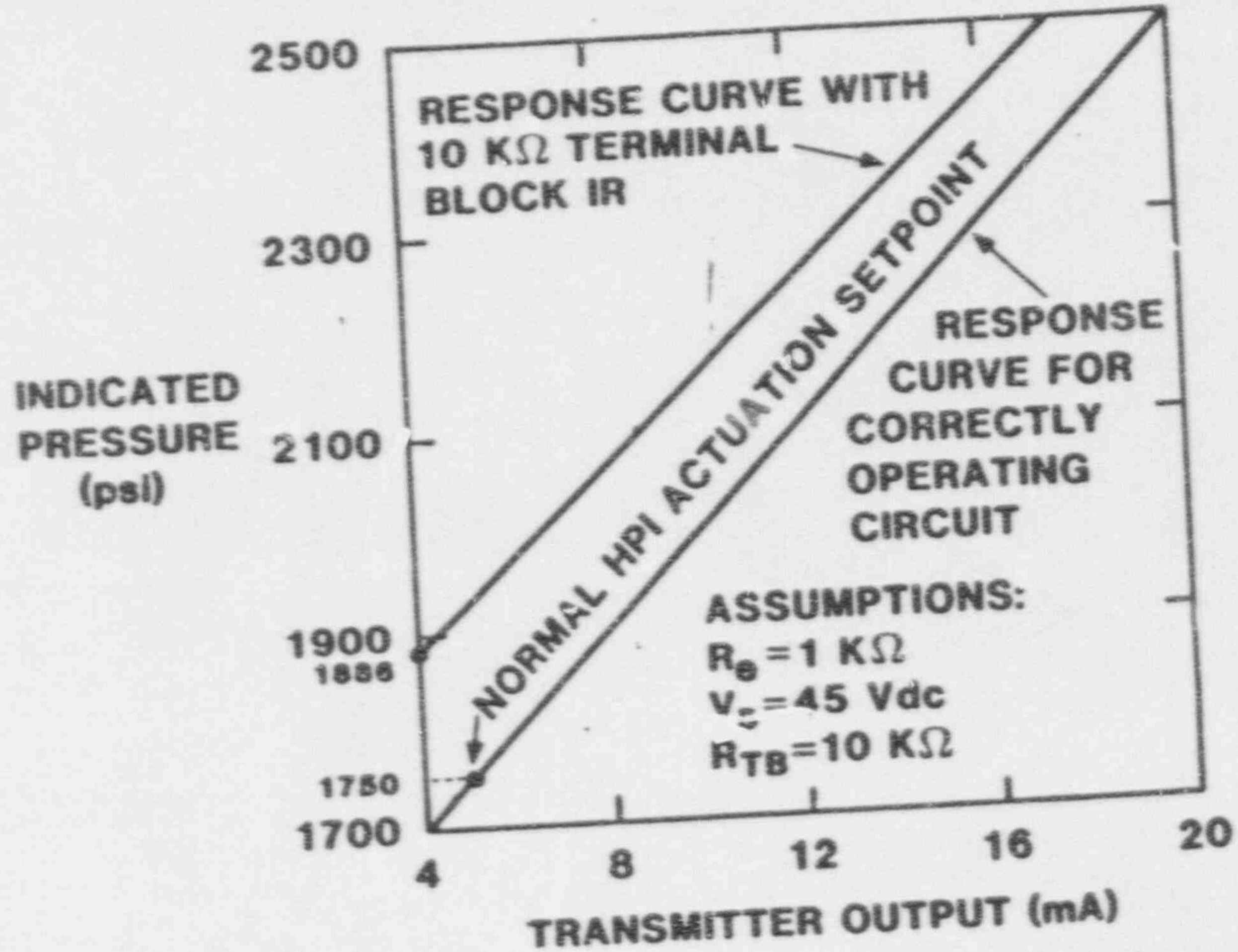


Figure 8-4: Indicated Pressure as a Function of Transmitter Output for a Correctly Operating Circuit and for a Circuit With Terminal Block Insulation Resistance Assumed to be 10 kohms

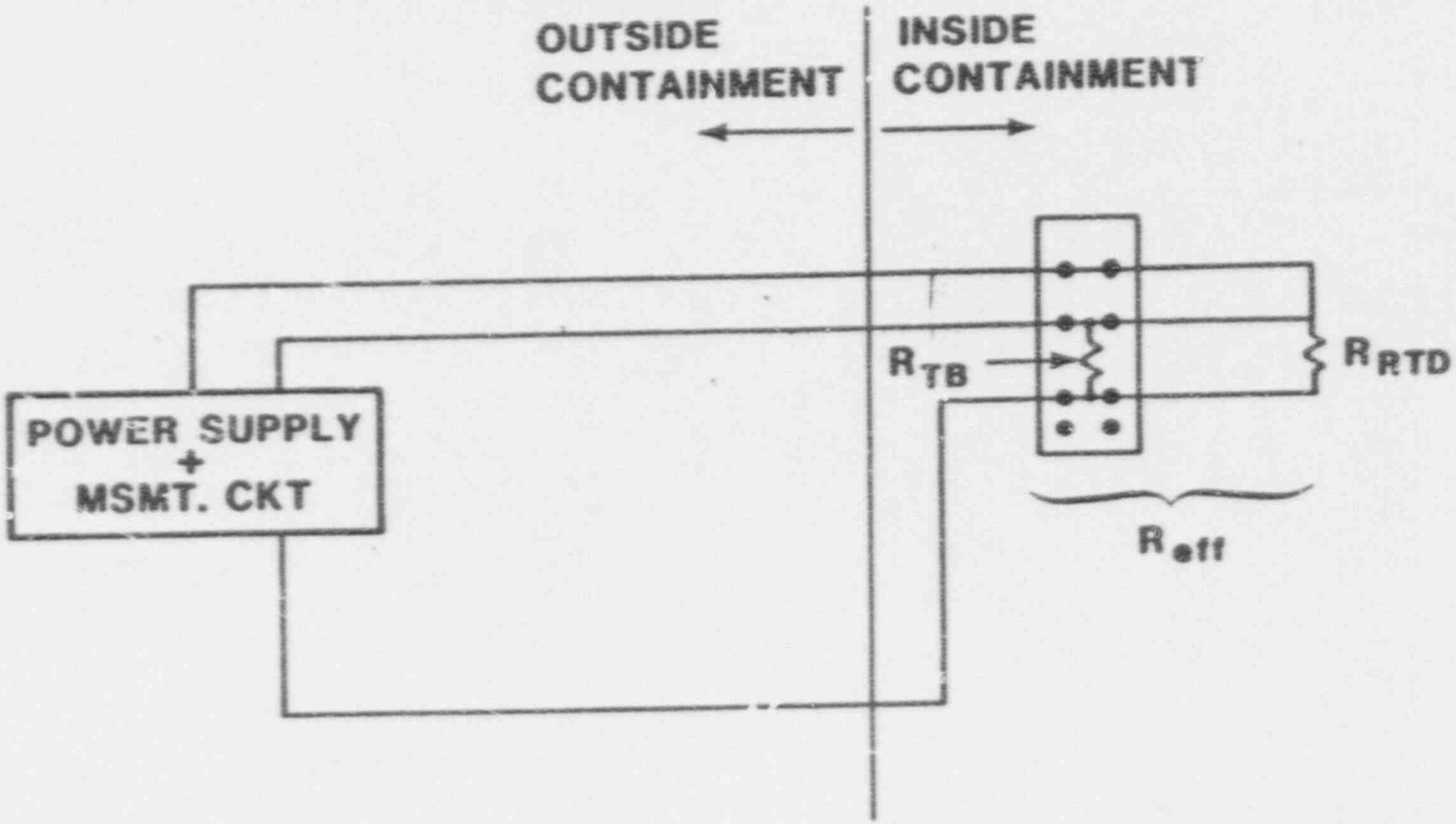


Figure 8-5: Simplified Block Diagram of a 3-Wire RTD Circuit Showing Parallel Connection Between Terminal Block Insulation Resistance and the Resistance of the RTD Sensing Element

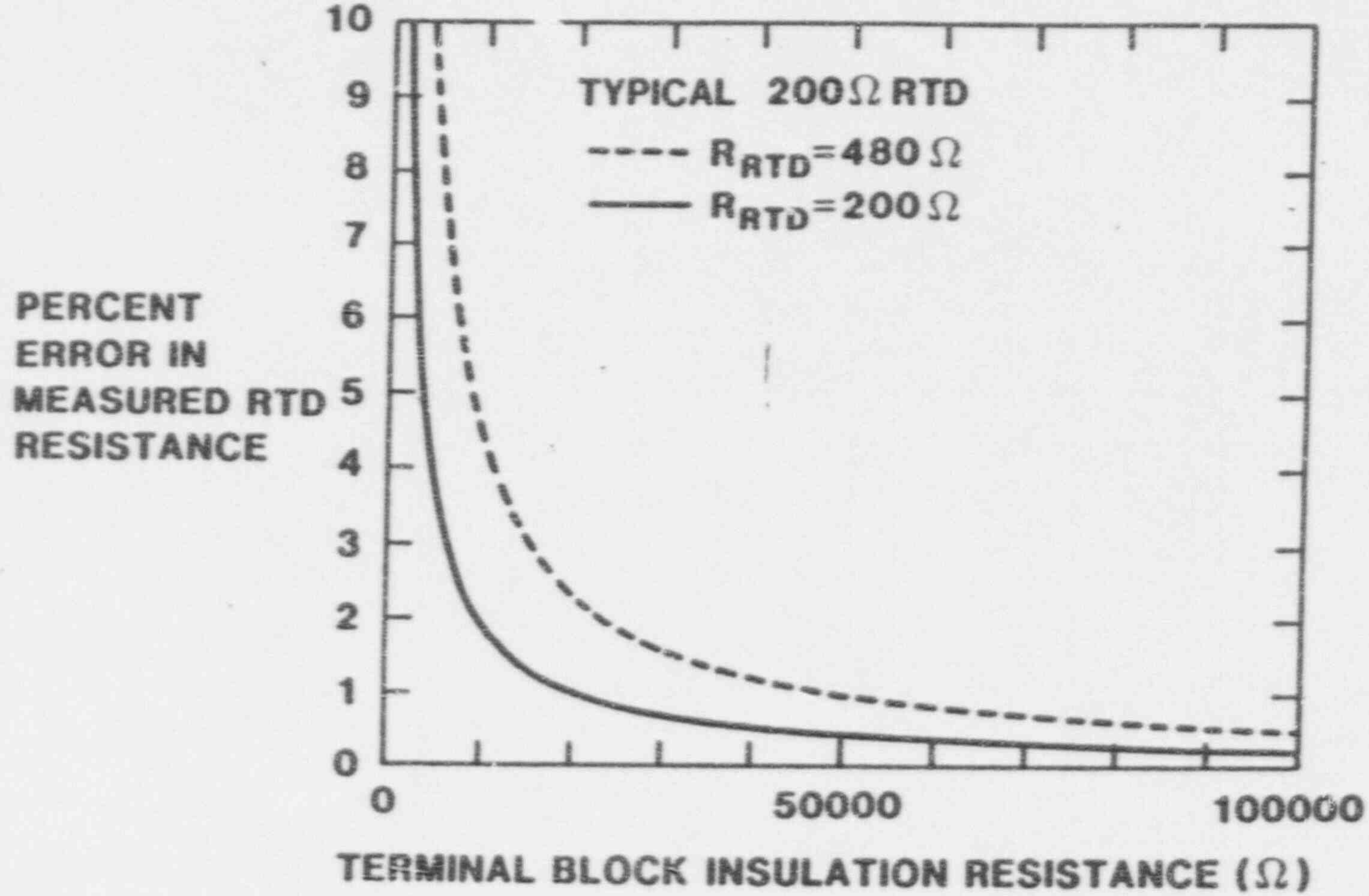


Figure 8-6: Percent Error in the Resistance Measurement of an RTD as a Function of Terminal Block Insulation Resistance

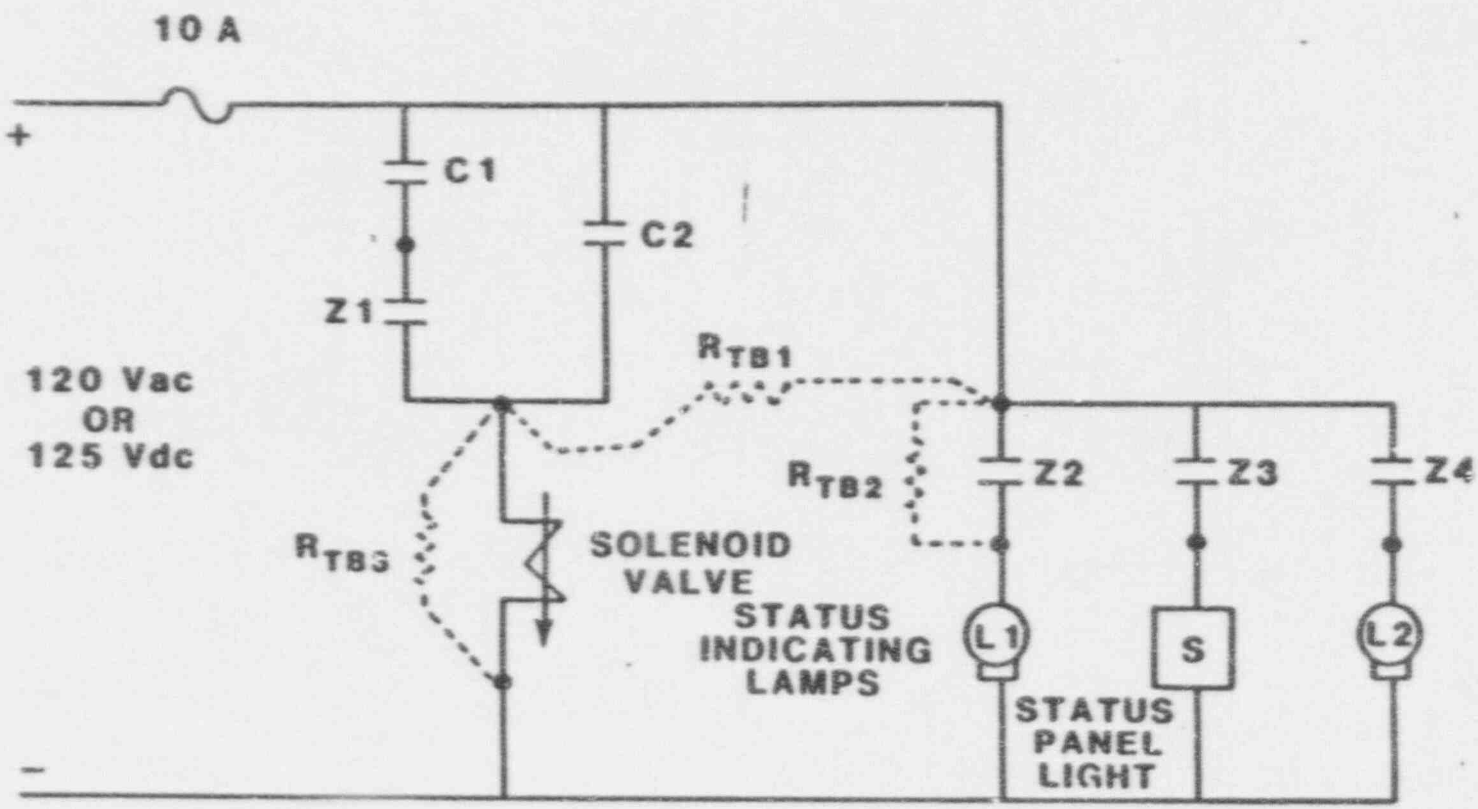


Figure 8-12: Simplified Circuit Schematic for One Possible Solenoid Valve Circuit

11.0 CONCLUSIONS

1. The primary application of terminal blocks in the nuclear power industry is instrumentation and control circuits.

2. Terminal blocks receive minimal quality assurance attention in selection, installation, inspection and maintenance activities.

3. Most industry qualification tests do not continuously monitor for low level leakage currents during LOCA simulation tests of terminal blocks. Without quantitative knowledge of these leakage currents, adequate analyses of their effects on instrumentation and control circuits cannot be performed.

4. Surface moisture films are the most probable explanation for degradation in terminal block performance during exposure to a steam environment. Because the existence of moisture films is highly dependent upon environmental conditions, test environments must realistically reflect the predominantly expected accident environments. For example, superheated test conditions may not accurately represent the terminal blocks' performance.

5. The use of voltage levels above actual use conditions in qualification tests of terminal blocks may be nonconservative with respect to the measurement of low level leakage currents which are the primary degradation mode of terminal blocks.

6. Terminal block leakage currents in a steam environment may degrade performance of instrumentation and control circuits to an extent sufficient to cause erroneous indications and/or actions.

7. Cleaning will probably not reduce leakage currents to a level acceptable for most instrumentation and control applications. The large, positive impact on terminal block performance that was originally believed to accrue from cleaning was not observed. Further, terminal block leakage currents were not significantly reduced by the application of either of two coatings tested.

PROBLEM TERMINAL BLOCKS

MARATHON 1600

TEST SUMMARY

PARAMETER	LIMITORQUE	WYLE/MARA.	WYLE/PP&L	WYLE/CECo
REPORT NO.	B0119	45603-1	45822-00	17657
DATE	APR 82	FEB 82	FEB 87	DEC 83
RADIATION	2.0E8	2.0E8	2.0E8	2.0E8
MOUNTING	UPRIGHT	FLAT	FLAT	FLAT
ENCLOSURE	DUMMY MOV	NEMA-4	NEMA-4	NEMA-4
AGING TEMP	280°F	248°F	248°F	248°F
AGING TIME	300 HR	443 HR	185 HR	932 HR
LOCA TEMP	312°F	350°F	360/330°F	345°F
PEAK TIME	30 MIN	3 HR	3 HR/3 HR	
VOLTAGE	250-2.8VDC MEGGER (IR)	132/264/528 CONTINUOUS	528VAC INTERMITTENT *	42/135DC/132AC CONTINUOUS
FPR/ACPT	>300IR	12/18/~~20~~ 25A FUSE	FUSES	LKG
RESULTS	INCONCL	FAIL	FAIL	HIGH LKG

* FUNCTIONAL CHECK WITH SMALL MOTOR LOAD

OTHERS

IEB's & IN's

IN 83-72 BUCHANAN

IEB 82-04 BUNKER RAMO EPA (KULKA)

TERMINAL BLOCKS
MARATHON
CRAFT REPORT

REPORT	DATE	AGING TEMP/TIME	DBE TEMP/TIME	FUSES LINE/LKG	RESULTS
WYLE-MARATHON 45603					
WYLE-PP&L FEB87					
WYLE-CECO 17657					
LIMITORQUE B0119					

SAFETY RELATED FROM MARATHON HAS STICKER. H.B. SAYS DIFFERENT FROM 1600s SUPPLIED TO LIM. COMM. GRADE.

ANOMALIES:

45603: cont. energ.,528 fail, 264 blew-not clear when replaced, 132 OK till near end of test when on restoratiuon of power, all blew!

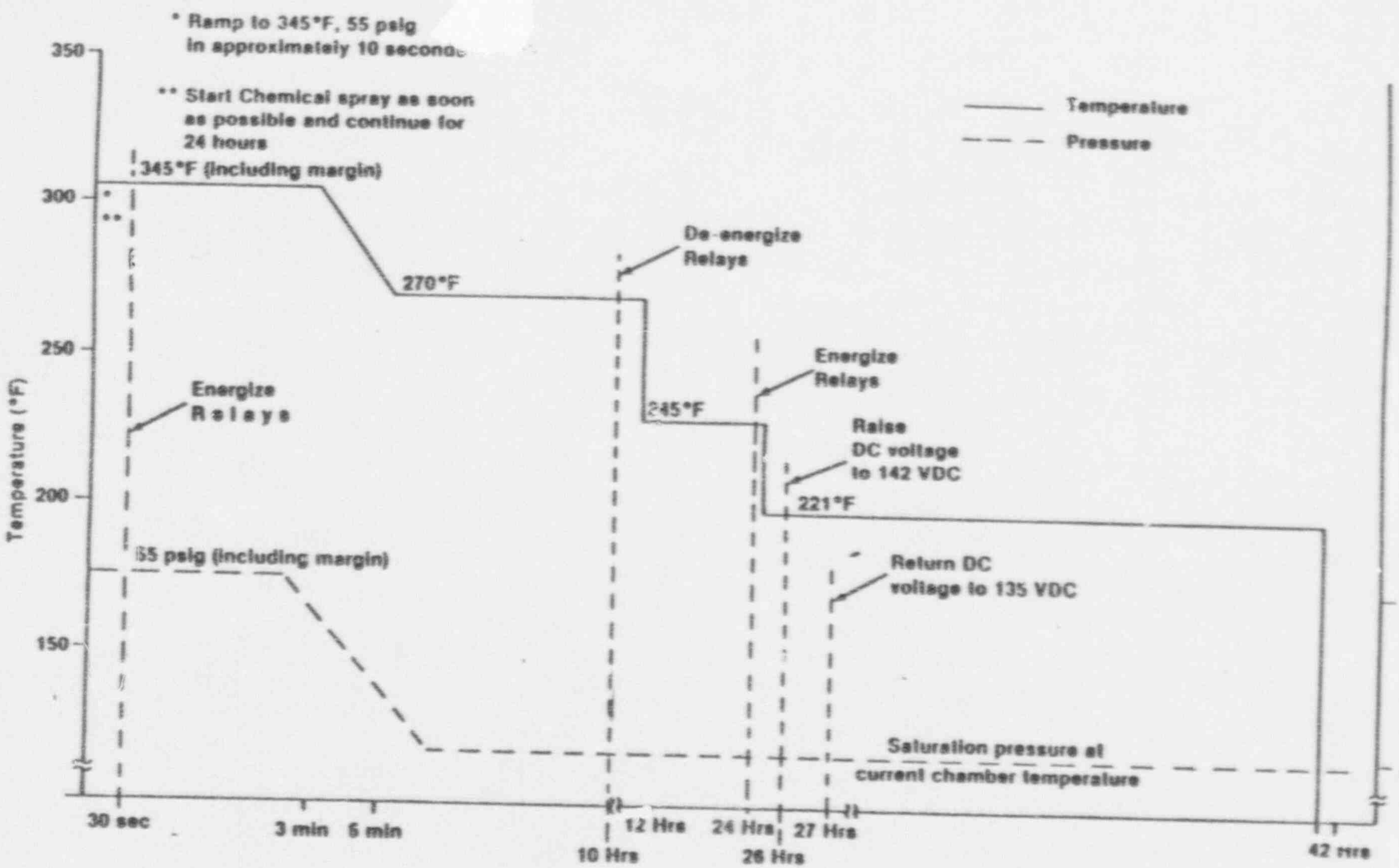
PP&L-1600s only, three, horiz failed on enrgizing after spray init.

B0119-only one 300 energ. although intermittently (worst case)
Curtis L data mis reported 700 ohm vice 700K
IRs taken wiyh as low as 2.8 VDC (500 V Megger)

NOte TBs mounted vertically out from base

HOW TO EVALUATE OPERABILITY ANALYSES

VOLTAGE DIVIDERS
FUSES
CONTINUOUS OPERATION
FAILURE MODES AND EFFECTS



ACCIDENT TEST PROFILE
Figure 3

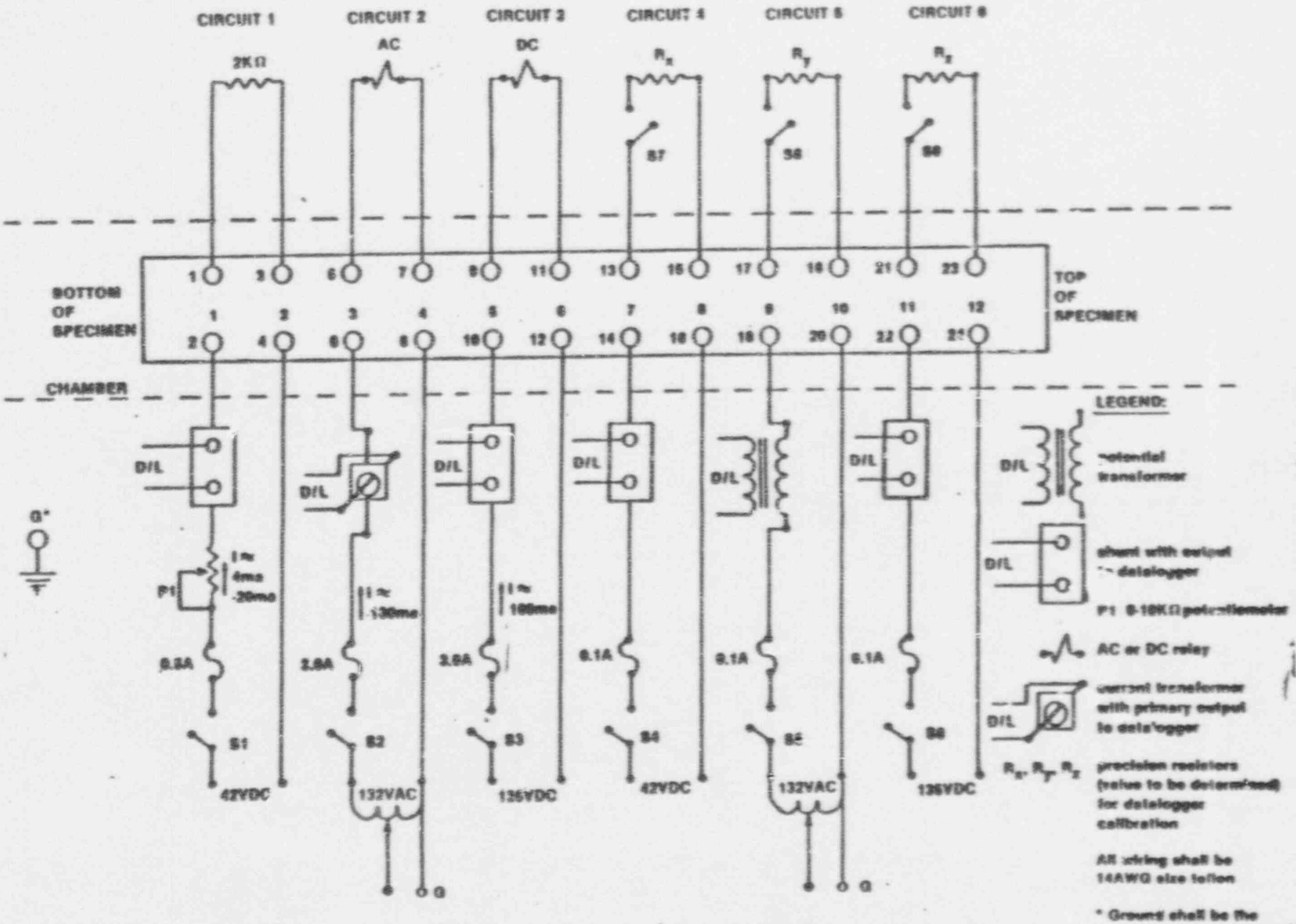


FIGURE II-1: Test Specimen Wiring

Table 2-1

Typical Radiation Damage Thresholds and Maximum Service Temperatures for Five Insulating Materials Used in Terminal Blocks Found in U.S. Nuclear Power Plants

Insulating Material	Radiation Damage Threshold (Rads(C)) [6]	Service Temperature °C (°F) [7]
Phenolics		
glass filled	10^{10}	160-190 (320-374)
cellulose filled	10^{8}-10^{9}	120-220 (248-428)
Alkyd		
glass filled	10^{9}	149-191 (300-376)
cellulose filled	10^{8}	191 (376)
Melamine (Resin)	10^{8}	
glass filled	10^{9}	204 (399)
cellulose filled	10^{7}	99-150 (210-302)
Diallyl Phthalate		
glass filled	10^{8}	204 (399)
cellulose filled	10^{7}	160 (320)
Nylon 61	10^{5}-10^{6}	130 (266) [8]

glass), the radiation levels quoted in Table 2-1 indicate that there will be minimal effect on the insulating materials normally used for terminal blocks by nuclear plant radiation doses (estimated doses: 5×10^{7} rad operating life and estimated 1.5×10^{8} rad accident).

The metallic terminals are typically stable to temperature and radiation levels which exceed the aging and accident environments postulated for nuclear power plants. Thus, we would not expect degraded performance of the conducting material based on pure radiation and/or temperature effects. There is, however, potential for material interaction problems such as corrosion or galvanic action to occur. The selection of metal coatings and base conductor material should be such that these effects are minimized in both the normal operating environment (e.g., 80-110°F and 10-100% RH) and the postulated accident environments which include steam and chemicals. One specific example would be to avoid the use of cadmium as plating material because in a steam-chemical spray environment it may be a reactant in a galvanic reaction.

KULKA MODEL 602JJ TERMINAL BLOCKS

AMPHENOL REPORT 123-2222

10 ma FUSE IN LEAKAGE CKT BLEW
DURING SECOND LOCA PEAK (340°F)

HAD TO REDUCE VOLTAGE FROM 600VAC
TO 370VAC TO KEEP FUSE FROM BLOWING

RETURNED TO 600VAC ON DAY 7

ANOMALIE NOT EXPLAINED

IRs AS LOW AS 100 OHMS AT 370VAC

NOT ENOUGH INFO TO RESOLVE IR NOR
ANALYSIS TO SHOW OPERABILITY OF
SERVED EQUIPMENT

ANOMALOUS SAMPLES AGED

OTHERS NOT AGED

6. Terminal Blocks, Raceways and Enclosures - EQ Concerns

(TB) - Installed directly below top conduit entries
in boxes without adequate test documentation for leakage current

(Anchor Darling) - Unqualified Nylon TBs. Unqualified for temperature.

(Anaconda Conduit) - Polyethylene copolymer jacket of flex conduit degraded while exposed to LOCA conditions (IN No. 83-72).

(Marathon) - 1600 Series TB found unqualified for circuits over 264 VAC in the drywell (In general there are no qualified TB's for 480V applications in the drywell).

(Stanwick) - Corroded terminals affecting qualified life. Junction boxes dirty and corroded.

LIMIT SWITCHES

TYPES - DOUBLE ACTING / SINGLE

-

USES - VALVE / DAMPER POSITION INDICATION

PRINCIPAL MFGRS

NAMCO CONTROLS — REPORTS HAVE MATERIAL CHANGE HISTORY BY DATE CODE

GASKETS - VELLEMOID / SR

QUALIFIED MODELS

EA180 QTR 105 323-74

EA 170 QTR 107 RAD'N ONLY 200 MRAD

D2400X PREDESSOR OF EA170

EA 740 323-74
EA 750 200 MRAD + SEIS (344-75)
EA 700 SEIS ONLY

INSTALLATION
- GASKETS
- ECSA's
- NYLON ROLLERS

- MODEL NO.
- CONFIGURATION SUFFIX
- DATE CODE

IR's SHUNTING OPEN CONTACTS

MICRO SWITCH DPST, 12 TSI-2 IN 33-72

LIMIT SWITCH PHYSICAL INSPECTION CHECKLIST

Component ID ________________ Reviewer: ________________

	Installed Condition		
	Agrees with Documented		
Documented Information	Yes	No	Comments
1. Location Bldg. ____ Room ____ Elev ____	___	___	
2. Manufacturer ________________	___	___	
3. Model No. ________________	___	___	
4. Mounting Description __________ ________________	___	___	
5. Orientation ________________ ________________	___	___	
6. Electrical Connection Type _____	___	___	
7. Housing Seals in Good Condition	___	___	
8. Ambient Normal Expected Temperature Range _________	___	___	(If ambient temperature exceeds normal expected conditions, verify that licensee has considered the elevated temperature in the qualified life evaluation)

General Comments on Physical Inspection:

Issue Date:

9. Position Switch/Limit Switch/Push Button Switches - EQ Concerns

- (NAMCO) - Lacked cable entrance seal
- (NAMCO) - Cover screws missing - Bad housekeeping

- (REES) - Push button - Lacked test report and evaluation for ambient pressure

SOLENOID OPERATED VALVES

TYPES - AC, DC, SINGLE SOL. / DBL SOL.
/USES 2 WAY, 3 WAY

ENERGIZED TO OPEN / CLOSE - VENT

N.E. N.D.

N.O. N.C.

FCV's

FCPV's

DEGRADABLE PARTS

ELASTOMERS - DIAPHRAGMS
- O-RINGS - PLUNGER SEALS
- COIL WIRE INSULATION

PRINCIPLE MANUFACTURERS

QUALIFIED MODELS

ASCO
AUTOMATIC SWITCH CO.

NP-1
206 381
ELASTOMERIC SUFFIX
"V" for VITON
E for EPDM

IN 84-68 { VALCOR
TARGET ROCK

DRESSER

LAWRENCE

ECSA's

SUBMERGENCE

SEALANTS - PIPE THREAD ETC

VENTS

SOV's

IN's 80-11 ASCO

82-52 DRESSER

TARGET ROCK

CCI

ASCO

84-23 ASCO

84-68 VALCOR, TGT ROCK

85-08 ASCO

85-17 ASCO HTX-8323

—

ASCO REPORTS

TR No. AQS 21678/TR REV A & B 7/79 , 80

323-74

382-72 NP-1 - 206381

(8300's)

30 DAY LOCA 346°F PEAK

TR No. AQR-67368 1982

323-74

30 day LOCA/HELB + MARGIN 420°F

PT 21 SALEM 206-381-6RU - INCORRECT SEATS

↑

6RU

—

SOLENOID OPERATED VALVE PHYSICAL INSPECTION CHECKLIST

Component ID ____________ Reviewer: ____________

Documented Information	Installed Condition: Agrees with Documented — Yes	No	Comments
1. Location Bldg. ___ Room ___ Elev ___	___	___	
2. Manufacturer ____________	___	___	
3. a. Model No. ____________	___	___	
b. Voltage ____________	___	___	
c. Configuration ____________	___	___	
4. Mounting Description ____________	___	___	
5. Orientation ____________	___	___	
6. Process Connection Type ____________	___	___	
7. Electrical Connection Type ____________	___	___	
8. Housing Seals in Good Condition	___	___	
9. Does Installed Device Experience a Significant Temperature Rise from Process?	___	___	(If yes, documentation must be reviewed to determine if the temperature rise was considered)
10. Ambient Normal Expected Temperature Range ____	___	___	(If ambient temperature exceeds normal expected conditions, verify that licensee has considered the elevated temperature in the qualified life evaluation)

General Comments on Physical Inspection:

Issue Date:

4. Solenoid Valves - EQ Concerns

(ASCO) - Coil replacement interval exceeded.

(ASCO) - File required conduit entrance seal for valves under high pressure; no seals found in field.

(ASCO) - File required sealed cable conduits with weep holes at low point; not found in field.

(ASCO) - Loose housing found which could allow the atmosphere to enter coil housing.

(DRESSER) - Valve Model No. 1525VX had unqualified PVC wire (No documentation)

(ASCO) - Model No. NP-8316-54V not qualified by type test, in that moisture seals were not provided at the cable entry.

(TARGET ROCK) - Internal temperature rise causing temperature of field run cable to exceed rating (IEB No. 84-68).

(ASCo) - File stated that all solenoid valves (ASCo) had to be tested once a month to insure proper opening and closing; while maintenance instructions said no maintenance was required.

(ASCo) - Valve containing viton dynamic seals, ASCo Model No. NP1, not to shift position after being exposed to > 20 MRads (IN No. 82-52).

(ASCO) - Model NP-1 has ethylene propylene seal elastomers that degrade when exposed to oils and greases (IEB No. 80-11).

(ASCo) - Models NP 8316 and NP 8344 failed during LOCA testing at Franklin (IN No. 84-23); attributed to elastomers sticking to valve metallic parts.

TRANSMITTERS

DPIS

PS

TS

ELECTRONIC PT, LT, FT
(ANALOG)

TYPICALLY 50 VDC, 10-50 ma or 4-20 ma

ACCURACY - UNITS, PERCENT

LOOP ACCURACY - CABLE, ZSA's, TB's - IR's

$\sqrt{\Sigma IR^2}$ - RANDOM

T/E's - RTD's
- T/C's

PRINCIPAL MANUFACTURERS | QUALIFIED MODELS

BARTON | 278 279 288(A)
SW's 580 SERIES
580 SERIES
XMTR's 763 LOT 1
764 LOT 2

(NE Series qualified)

FOXBORO

ROSEMOUNT | 1151
1152 → DOR
1153

RAYCHEM
ECSA's — Elec conductor seal assemblies } connect }

RADIATION FIELDS / TEMP

O-RINGS

TYPE OF WIRE

TRANSMITTERS (INCL. P'S:)

IN's

82-11	W NSSS SUPPLIED WR PT	HELB ERROR
82-52	BARTON (W SUPP)	LOT 4 GRA
83-72	BARTON	PART D4R-29098
	BARTON	763
	BARTON	764
	BARKSDALE	PS B2T, D2H
	SOR	PS 5N, 12N

TRANSMITTER PHYSICAL INSPECTION CHECKLIST

Component ID No.: ________________ Reviewer: ____________

Documented Information	Installed Condition Agrees with Documented Yes	No	Comments
1. Location Bldg. _____ Room ___ Elev ____	___	___	
2. Manufacturer ________________	___	___	
3. a. Model No. ________________	___	___	
b. Range/Type Code ________	___	___	
c. Serial No. ______________	___	___	
4. Mounting Description ______ ____________________________	___ ___	___ ___	
5. Orientation ______________ ____________________________	___	___	
6. Process Connection Type ______ ____________________________	___	___	
7. Electrical Connection Type ____ ____________________________	___	___	
8. Housing Seals in Good Condition, Covers in Place	___	___	
9. Does Installed Device Experience a Significant Temperature Rise from Process?	___	___	(If yes, review documentation to determine whether considered)
10. Ambient Normal Expected Temperature Range ________________	___	___	(If ambient temperature exceeds normal expected, verify that qualified life evaluation considered)

General Comments on Physical Inspection:

Issue Date:

7. <u>Transmitters - EQ Concerns</u>

(General) - Qualified life exceeded for parts or whole, Calibration life exceeded

(Rosemount) - Pressure, level and flow transmitters lacked conduit weepholes; had wrong location and wrong model

(Rosemount Level Transmitters) - No record of O ring replacement during maintenance.

(Rosemount 1154) - File indicated a qualified life of 15 years but maintenance requirements did not call for a replacement at that time.

(Foxboro) - Conductor insulation degradation found on Foxboro Model E Controllers, IN No. 86-52

← usually in a non harsh environment

8. Level Switch /Pressure Differential Switch - EQ Concerns

(Static-O-Ring) - (SOR) pressure switch lacked cable entrance seal

(Magnetorol) - EQ File indicated no qualification required, however, file did not address effects of switch failure on other EQ equipment.

(Static O Ring) - Series 102 and 103, erratic tripping below specified drift pressure setpoints, IEB No. 86-02, IE No. 86-47.

(Static O Ring) - DP switches exhibited erratic tripping due to corrosion of O rings also exhibited drifting setpoints (IEB No. 8602)

(Barksdale) - Pressure switches Models B2T and D2M experienced blown seals that allowed water to accumulate in the switch housing, and as a result, exhibited electrical shorts across the microswitches.

(Static O Ring) - Pressure Switches, Models 5N and 12N failed in LOCA testing due to blown in gaskets and elastrometric diaphragms rupture (IN No. 83-72).

RAYCHEM SPLICES

REPORTS

TYPES - WCSF-N
- NMCK
-

CONFIGURATIONS

- IN LINE
- V
- BREAKOUTS
- BOLTED
- BUTT-SPLICE - INSULATED & UNINSULATED
- BOOTS
- OVERSLEEVES

PROBLEMS IN 86-53

- OVERLAP < 2"
- BRAID
- USE RANGE
- SHRINKAGE
- BENDING - 5x Raychem sleeve and/or exceeding Bend Radius of Conductor
- SURFACE PREP
- ADHEASIVE
- OVERSLEEVES

- SHIMS
- PADS (BOLTS)

INSPECTION

TI 2500/17 9/22/86

MODULE 92701 FOLLOWUPS

-INCLUDING IEN's

CONDULET

LIMITORQUES

SMALL JCN BOXES

Nuclear Utility Group
NUGEQ REPORT 1/4", BENT IN HALF ETC.

—

ANALYSIS USING NUGEQ DATA

OTHER TYPES OF SPLICE INSULATION

RTV's

- TAPE - HV & LV

HV - KERITE WHITE NYLON WRAPPING

- OKONITE

(NEW RAYCHEM HV NMCK) - Cont Spray - Safety Inj

TYPICALLY ON 4KV/5KV CSPM's, SIPM's RHR PM3. ETC

LV - SCOTCH 33+ - INNER

SCOTCHCO PUTTY - FILLER DOR, 50.49(1)

SCOTCH 70 - INNER

SCOTCH 23 - OUTER PLAIN ELECTRICAL TAPE

- INSULATED BUTT CONNECTORS - AMP

NYLON, GE-F01 EPA's - FAILED in WYLE/CECO

IN 86-124

- QUALIFIED - KYVAR Amp Splices (LV)

3. Cable Splices - EQ Concerns

- (Raychem WCSF-N) file did not address Beta radiation for unshielded splices.

- (AMP splices) Lack of qualification traceability for nylon insulated splices.

- (AMP splices) Found degraded prior to the end of their qualified life at Dresden.

- (Raychem) Files too general. No specific consideration for high leakage currents and low IRs affecting instrumentation circuits. No plant specific acceptance criteria identified.

- (Raychem) Report made generic qualification statement of similarity for all models; however, not clear on degree of similarity, as no discussion or analysis to support similarity existed. No reference to polymer materials of construction.

- (American Pamcor) Test report did not establish adequate similarity between tested Model No. 52979 and other specific models in plant.

- (Raychem) - Less than required overlap of seal length on cable insulation.
  - Splicing over braided material/unqualified substrate.
  - Exceeding bending radius requirements of shrink tubing.
  - Use of wrong kits caused stretching of tubing and inadequate seal.
  - Lack of shims on small diameter cables.
  - Flexing of splices while hot caused damage to surface of seal.
  - Lack of QA/QC hold points.
  - Site procedures do not conform to RayChem instructions.

DATE	REPORTS NO.	AGING	RADIATION	PEAK/T...E/pH (of)	SAMPLE DESC	CABLE
1973	71100	121°C, 168 hrs	100 Mrads 200	360°F, 100 days, 10	In-Line Splice WCSF-N (6")	XLPE EPR/Neopr
1974	FC4033-3	150°C, 168 hrs	150 Mrads 200	357°F, 30 days, 9.5 11.0	In-Line Splice (6") Transition Splice WCSF-N/-4 molded parts	XLPE
1978	EDR5019	150°C, unaged 168 hrs 1500 hrs	200 Mrads	DOUBLE PEAK LOCA 350°F, 21 days, 10.5	In-Line Splice WCSF-N (6")	XLPE
1980	EDR5011	150°C, 168 hrs	163 Mrads	DOUBLE PEAK LOCA 340°F, 30 days, 10.5	In-Line Splice WCSF-N (6") on EPR/HYPALON WIRE	EPR/Hypal
1980	EDR5015	150°C, 168 hrs	200 Mrads	DOUBLE PEAK LOCA 340°F, 30 days, 10.5	- NMCK - Motor Connection Kit - NESK - Cable End Sealing Kit	XLPE
1981	WYLE 58442	150°C, unaged 1000 hrs 1500 hrs	200 Mrads 290	390°F, 30 days, 10.5	In-Line Splice WCSF-N ("L") NCBK - CABLE Breakout Kit NESK - END Sealing Kit NMCK - Motor Kit	XLPE
1982	WYLE 58722	150°C, 767 hrs	215 Mrads	DOUBLE PEAK LOCA 442°F, 30 days, 10.5	In-Line Splice WCSF-N (6") NPKV - Stub Connection Kit NPK - Plant Splice Kit Transition Sleeve - 202B	XLPE
1983	EDR5088	ANCI-C119.1			In-Line Splice WCSF-N (3") One Inch Seal (Non-Accident Criteria)	XLPE

EDR 6057 * Q-[illegible]

* This list is a compilation of major qualification reports. These reports reflect the overall development of the qualification program to meet the then current industry requirements. A complete list of reports is detailed in Raychem's Nuclear Product Guide I.

WALKDOWN CONSIDERATIONS

PLANNING PHASE

- SUGGEST PARTIAL PREPS/FASTENER LOOSENING/REMOVAL PRIOR TO CONTAINMENT ENTRY.
- CONSIDER ACCESSABILITY BUT KEEP IN MIND THAT ITEMS WHICH ARE INACCESSIBLE OR OBSTRUCTED BY INTERFERENCE MAY NOT HAVE BEEN ADEQUATELY INSPECTED BY THE LICENSEE...

- ESCORTS
  - KNOWLEDGE OF PLANT
    - SYSTEMS
    - FUNCTION
    - LOCATION/ACCESS
  - KNOWLEDGE OF EQ
  - ELECTRICIAN(S)
  - HP TECHS

ASSISTANTS
- RECORDER

DONT TOUCH
- ENERGIZED

- TOOLS
  - CLIPBOARD
  - BAGS
  - FLASHLIGHT
  - SAFETY GEAR
  - INSPECTION MIRROR
  - MICRO CASSET
  - POLAROID
  - PENS/PAPER
  - RADCON / XEROX

- USE PLANT'S TOOLS

WALKDOWN

- AGREEMENT - ENSURE THAT A LICENSEE REP WITH SOME AUTHORITY OBSERVES WHAT YOU DO - SECURE AGREEMENT AS TO THE CONDITIONS OBSERVED - RECORD ACCURATELY DOCUMENT AGREEMENT - NAME/TITLE OF LIC. REP

- UNESCORTED ACCESS
  - NOT REQUIRED OR DESIRED FOR NRC HQ / CONTRACTORS

CONTRACTOR CONTROL

REGULATORY MATTERS - PRE BRIEF
ARGUMENTS - REFEREE

MASTER LIST VALIDATION

REVIEW OF PROCEDURES TO DEVELOP & MAINTAIN
" " (B)(2) ANALYSIS
" " DELETION JUSTIFICATIONS

GO OVER EOP'S WITH AN EQ EXPERT AND OPS EXPERT (MAY BE SAME PERSON)

SELECT ITEMS AT RANDOM
VERIFY ALL ON LIST OR JUSTIFYABLY REMOVED
- NOT IN HARSH ENV
- " ~~[illegible]~~ " FOR ACCIDENT ETC

* 0588 [illegible] TRICK

REGION II RESPONSE TO ALABAMA POWER COMPANY REQUEST FOR DOCUMENTS IN CONNECTION WITH THE FARLEY EQ CIVIL PENALTY HEARING

#4 / Levis

REGION II CONTACT: BRUNO URYC, FTS 841-4192

DOCUMENT TITLE: EQUIPMENT QUALIFICATION SEMINAR

70pgs

DOCUMENT DATE: 08.26.87

DOCUMENT RECEIVED FROM: W. LEVIS

TYPE OF DOCUMENT: TRAINING MATERIAL

RESPONSIVE TO ITEM NO: 39

EXEMPTION CLAIMED: NO

YES - __________

39-6

Mark Jacobus

EQUIPMENT QUALIFICATION SEMINAR

Sponsored by:

U.S. Nuclear Regulatory Commission

Presented by:

U.S. Nuclear Regulatory Commission
and
Sandia National Laboratories

August 26-28, 1987

Albuquerque, New Mexico

Sandia National Laboratories

Technical Review of EQ Files

Overview

Environmental

--Aging
--Thermal
--Radiation
--Operational

--Seismic (will not be covered)

--Accident
--Radiation, beta and gamma (covered with radiation aging)
--Steam
--Chemical Spray

--Post-accident

--Submergence

Assessment of the adequacy of the above requires additional information as follows:

--Functional performance requirements and data
--Accuracy requirements and data
--Insulation resistance data, if needed

--Qualification basis
--NUREG-0588 Category I or II
--DOR Guidelines
--10CFR50.49

--Similarity

--Margin

A simple (and perhaps idealistic) interpretation of qualification which envelops virtually all technical qualification problems is as follows:

Testing, analysis, or operating experience data from identical or similar equipment which verifies that the equipment is capable of meeting its functional performance requirements in all environments to which it might be exposed.

Aging

Objecti... : to put equipment in its end-of-qualified-life state

Thermal Aging

Usually established by Arrhenius plot or calculations

Arrhenius equation:

time

$$\frac{t_2}{t_1} = \exp\left[\frac{E_A}{k_B} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right]$$

T = temperature in degrees Kelvin (K)
t = time (any units)
E_A = activation energy (eV)
k_B = Boltzmann's constant (8.617×10^{-5} eV/K)

How do we determine activation energy?
- --Put samples in aging ovens at various temperatures.
- --Periodically remove samples and measure degradation in some property (tensile elongation, dielectric strength, ~~etc.~~).
- --Choose some "standard" of degradation, e.g. 50% of the original value, and find the time to that level of degradation at each temperature.
- --Plot log(t) vs 1/T (absolute temperature, for the chosen endpoint. Other "standard" endpoints may also be plotted.
- --Activation energy is the slope of the resulting line times Boltzmann's constant if the line is very nearly linear, indicating the sample degradation is dominated by a first-order chemical reaction.

The Appendix gives values of activation energy for many materials from EPRI NP-1558 and may be used for general guidance.

Example plots (from Rockbestos) are shown on the next two pages.

Relationship of Activation Energy and Life

--Activation energy does not give any information about material life.

Example: A claim that because a material has a high activation energy, it has a long life is not valid.

Activation energy measures the amount of acceleration that occurs when a material is aged at a higher temperature.

is slope of line

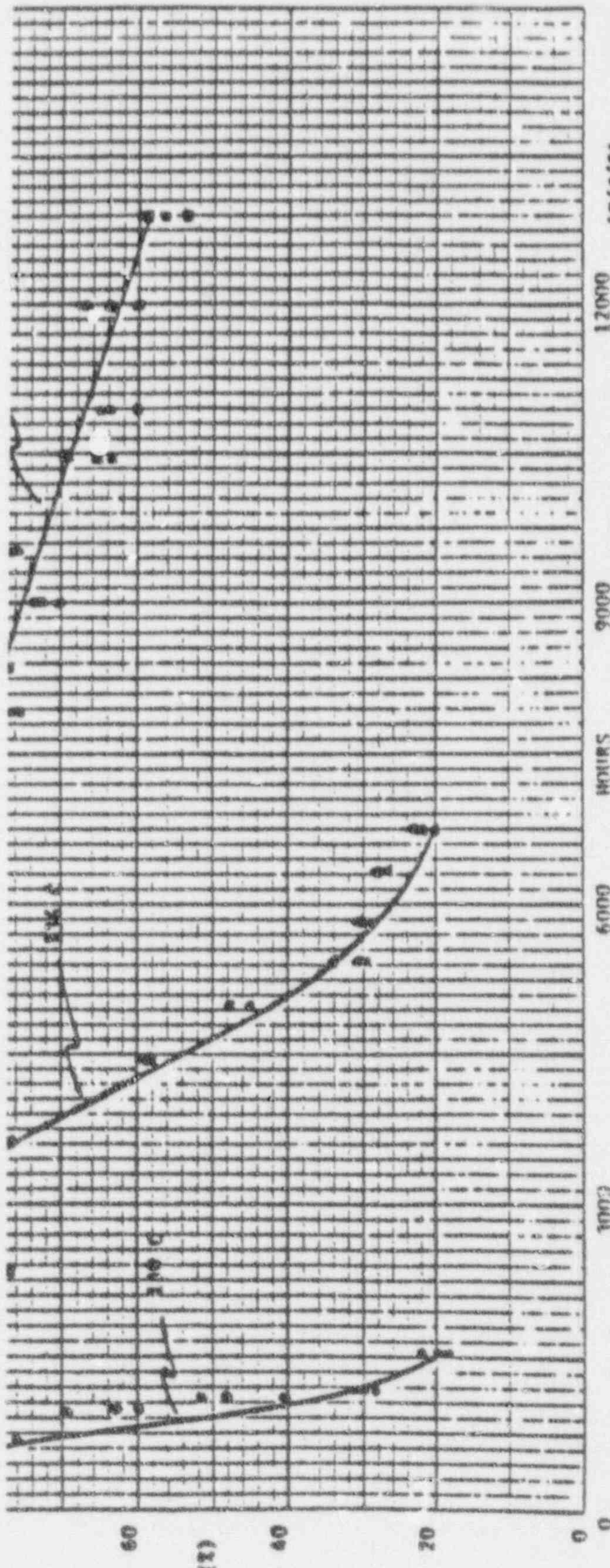
5 hr @ 150°C, 4300 hr @
resent the same amount of
% of the original value. The
e fferent times at
ilar times/temperatures for
ation.

criterion which puts a limit
n degrade before the material
orming its intended
for a cable might be when it
strength, when its insulation
a value where the cable is
ther criterion one might have
r point is that the
determined by the
end-of-life for nuclear
device is no longer capable
n in an accident environment
However, this criterion is
s (for practical reasons).
urer is to first determine
pically some enveloping
of the materials involved,
the device (often 40 yr, but
aging temperature is chosen
tations, and practicality;
ion, the artificial aging
terial with the limiting

e?

ial to be in a condition
lly aged in the plant at the
d qualified life. After
ent tested and checked for
he material must have been at
ts true end-of-life for the
bability, more aging could
Conversely, if the material
nd may not be able to meet
hat many other effects,
have caused the failure). In
erials in the device might

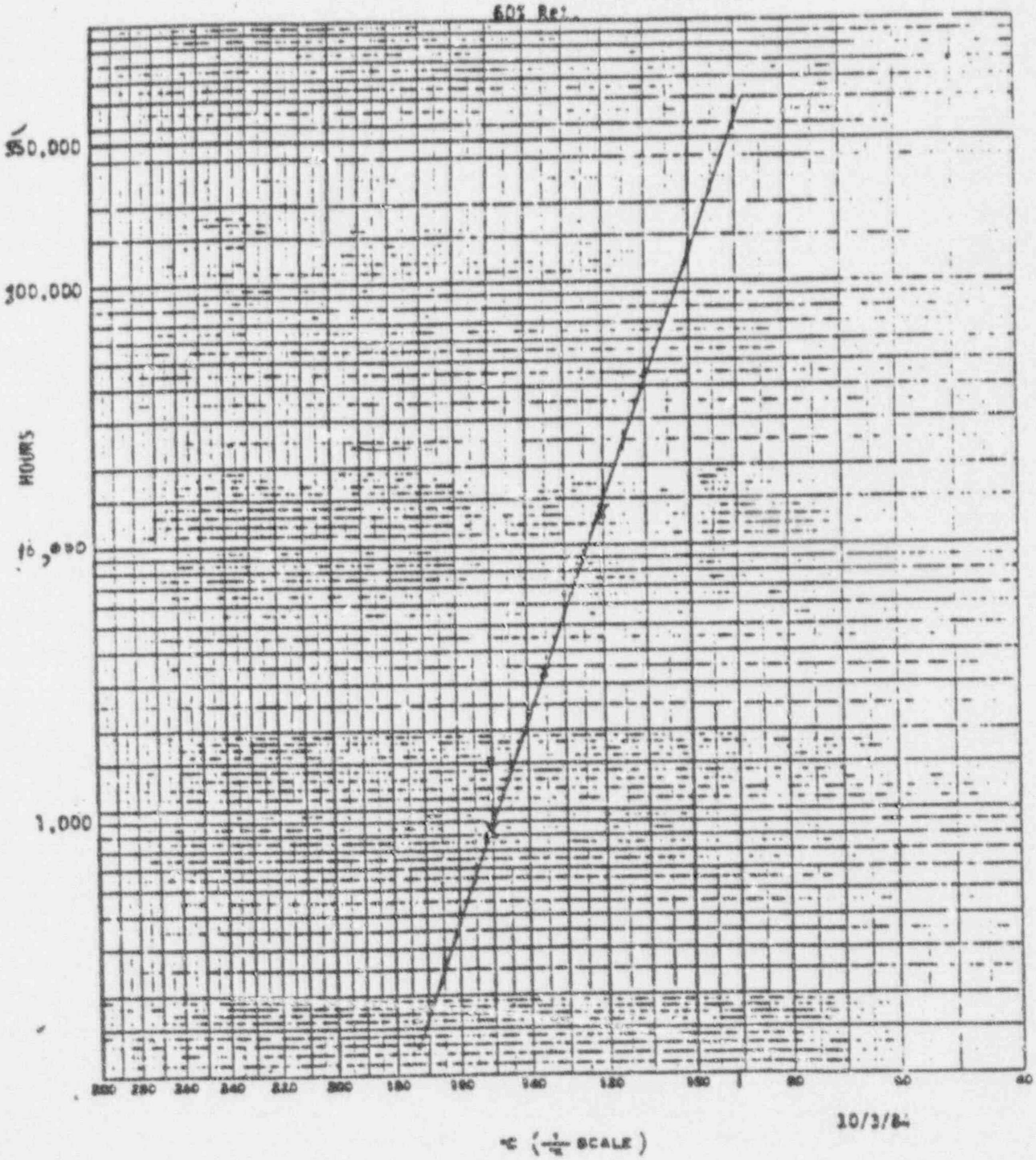
vary widely, the aging of
ccelerated more than the
former to be aged to much
qualified life. In some
ilures of the device which
life aging failures.
d to limit overaging, with



KXL-760D

$Lny = 15,564 \left(\frac{1}{k}\right) - 29.9439$

60% Ret.



--Preaging of materials that have low activation energy prior to final assembly of the device with subsequent aging of the complete device.

--Replacement of high activation energy materials at an appropriate time during aging so that they will be aged to the correct qualified life.

NOTE: Most manufacturers do not wish to disturb seals or gaskets used on a device, which can limit the usefulness of the above methods in some cases.

--Selecting a shorter qualified life for the overall device, but requiring replacement of the subcomponents with the lowest activation energies at appropriate intervals.

NOTE: It must be emphasized that the above does not imply that the materials with low activation energies are necessarily anywhere near their true end-of-life, only that the aging performed is insufficient to demonstrate a longer qualified life.

In many cases, none of the above techniques are used and the overaged parts are used throughout the rest of the test sequence.

Other notes on thermal aging:

--Some materials may exhibit non-Arrhenius behavior.

--10°C rule may also be used, i.e. for every 10°C rise in temperature, the life decreases by a factor of 2. However, this method may be somewhat less precise than the Arrhenius method, and therefore it is used sparingly. It may also be modified, to say a 7.3°C rule, based on specific material data.

--In some cases, a utility might use a number of different normal aging environments to cover various operating conditions of the plant when the temperatures are different. In effect, a summation procedure is used in the calculation of qualified life and the Arrhenius equation is modified slightly. This approach is often used if the testing done does not support a qualified life at some enveloping temperature.

--The DOR Guidelines contain the least strict thermal aging requirements. Section 5.2.4 has been interpreted to mean that in virtually all cases, analysis and/or separate effects tests are permissible for thermal life calculations. When thermal aging was not included in the test program, there is no real basis to define end-of-qualified-life in terms of a measurable parameter. Consequently, utilities may choose a definition for end-of-qualified life which will result in a desired qualified life. In general, a basis of below 50% retention of a given property would need good justification.

--The uncertainty associated with the Arrhenius calculations should be recognized and understood. For example, consider an aging time of 100 hours, an aging temperature of 130±3°C, an ambient temperature of 50±5°C, and an activation energy of 1.0±0.1 eV. The range of potential lives from this data is from 3.52 years to 68.6 years! Normally, the life should be determined in a conservative fashion, but this example demonstrates that even slight variations in parameters can make extreme differences in qualified life. The reason is, of course, that the exponential in the Arrhenius equations greatly magnifies uncertainty.

Aging and Accident Radiation

Normally, the total integrated dose (TID) of radiation (aging + accident) is applied at one time using a fixed dose rate which is much higher than the normal aging dose rate and may be on the order of the peak accident dose rate. This type of exposure uses an equal-dose-equal-damage assumption, meaning any possible dose rate effects are neglected (except that margin might be added to the TID to account for dose rate effects).

Applying the total dose at one time at a fixed dose rate is consistent with IEEE 323-1974 and IEEE 383-1974 (for cables). IEEE 383-1974 does state that the dose rate should be less than 1 Mrad/hr for insulating materials. 10CFR50.49 specifically requires consideration of dose rate effects when establishing radiation service conditions. The DOR Guidelines do not require consideration of dose rate effects.

The following materials have been demonstrated to have some dose rate effects.

Ethylene Propylene Rubber (EPR)
Polyvinyl Chloride (PVC)
Low Density Polyethylene (LDPE)
Chlorosulfonated Polyethylene (Hypalon)
Chloroprene

For these materials irradiated to a given total dose, the amount of degradation tends to increase as the dose rate is lowered (up to a point, depending on the given material).

In addition, 10CFR50.49 and NUREG-0588, Category I qualifications are required to consider synergistic effects (dose rate effects may be thought of as one type of synergistic effect). Materials that have been demonstrated to show significant synergistic effects between thermal and radiation aging are as follows:

Low Density Polyethylene
Polyvinyl Chloride

For these later two materials, simultaneous radiation and thermal aging is much more severe than sequential aging. Radiation followed by thermal is best if sequential testing is employed. Both of the above materials are in very limited use inside containments and in virtually all cases where they are used, qualification is to the DOR Guidelines, which does not require consideration of synergistic effects. In these cases, we have to rely on some sort of maintenance/surveillance to detect severe degradation. However, we don't really know what parameters are important in such a program... Current Sandia research is addressing this question.

Beta-Gamma Equivalence

All regulations support using a gamma source to simulate both the beta and gamma radiation. Beta is considered important for exposed materials (primarily cables). Most organic materials other than cables are well shielded from beta radiation, which has very little penetrating power.

Few significant problems have been found in this area. Even when beta radiation is not well addressed in a file, the utility can usually make valid arguments for neglecting its effects.

One possible sticky point: taking credit for beta shielding by a cable jacket when the integrity of the cable jacket is not verified at the end of the test.

Example: In the Rockbestos tests, neoprene jackets were cracked enough to see the insulation on the cables below, but this is not reported in the qualification test report because Rockbestos does not claim any credit for the jacket. One utility, not knowing about the cracked jackets, took credit for the jacket as a beta radiation shield.

Operational Aging

--Generally cycle devices a given number of times
Only necessary if some failure mode can be reasonably postulated based on cycling. Examples: cables don't really need to be cycled, but solenoid valves should be cycled.
--No major problems known in this area.

Seismic

--Not covered by environmental qualification.

Accident Simulation

Steam Exposure and Chemical Spray

All regulations require steam testing if equipment is to be exposed to a steam environment. This is the one area where even the DOR Guidelines are fairly rigid, stating the following:

"The choice of qualification method employed for a particular application of equipment is largely a matter of technical judgement based on such factors as: (1) the severity of the service conditions; (2) the structural and material complexity of the equipment; and (3) the degree of certainty required in the qualification procedure (i.e. the safety importance of the equipment function). Based on these considerations, type testing is the preferred method of qualification for electrical equipment located inside containment required to mitigate the consequences of design basis events, i.e., Class 1E equipment... As a minimum, the qualification for severe temperature, pressure, and steam service conditions for Class 1E equipment should be based on type testing... Exceptions to these general guidelines must be justified on a case-by-case basis."

Chemical spray is usually included in the steam test if it is a realistic service conditions. This is true even in older tests, although the DOR Guidelines do allow analysis for chemical spray qualification. Few problems have been found with qualification for chemical sprays, although some minor problems have been identified with facilities performing testing, primarily in quality assurance verification that sprays have been properly determined and mixed. The approximate concentrations of chemical reagents to mix IEEE 323-1974 standard chemical spray is as follows (IEEE 323-1974 spray often used as an enveloping condition):

17.3 g/l of H_3BO_3
10.7 g/l of NaOH
10.1 g/l of $Na_2S_2O_3$ OR 15.2 g/l of $Na_2S_2O_3 \cdot 5H_2O$
NaOH to make pH of 10.5 at 77°F

Steam testing is an area where many problems have been identified:

--Failure to perform a steam test on a configuration similar to the installed configuration (similarity/installation discussion later).
--Failure to monitor appropriate functional parameters during the steam test (more discussion later).
--Failure to envelop required accident parameters.

Example: Namco limit switches were tested with cable leads in sealed conduit such that no moisture could enter the limit switch through the conduit. An acceptable installation is thus to use a conduit seal to prevent moisture entry, but seals may not always be used.

In some cases, deviations may be successfully justified. Example: A thermal lag analysis may be used to show that a short duration temperature transient not enveloped by the test actually results in lower peak temperatures inside a device than does the testing performed over a much longer period.

Example: It is often possible to argue that the orientation of a device is not important during a steam test, such as for a pressure transmitter that is essentially sealed from the steam environment by gaskets or "o"-rings. This argument would perhaps be more difficult for terminal blocks or motor operators, whose orientations may be more critical during testing.

Although failure to envelop required accident parameters seems rather straightforward, it may be complicated by several factors. Rarely will a utility have non-enveloping conditions stated on the SCEW sheet without some analysis of why the deviation is acceptable (see thermal lag analysis example above). However, the important part of the review is to make good engineering judgements of the technical validity of the arguments presented and to be able to provide appropriate questions where the arguments appear weak.

Example for discussion: At Oyster Creek, the conduit seals normally required for Namco limit switches (see above example on Namcos) were not used outside containment. Upon questioning the rationale, utility personnel stated that the accident environment at the location of the limit switches (193°F and 100% relative humidity) did not constitute steam service as defined by the DOR Guidelines and hence did not require a steam test. The walkdown inspection revealed that the limit switches were at the lowest point of a run of about five feet of conduit. What do you think?

Discussion of Saturated vs. Superheated Steam

Saturated steam is steam which is at a temperature and pressure where both liquid and vapor can coexist at equilibrium. Some saturated temperature/pressure conditions are as follows:

Temperature (°F)	Pressure (psia)
70	0.363
100	0.950
150	3.722
200	11.53
212	14.70
250	29.82
300	66.98
350	134.5

Relative humidity is the ratio of the partial pressure of water vapor to the saturation pressure of the steam at the given temperature.

Example: A water vapor/air mixture has a total pressure of 14.7 psia. What is the relative humidity if the temperature is 100°F and the vapor has a partial pressure of 0.5 psia (i.e. vapor accounts for 0.5 psia of the total pressure and air accounts for 14.2 psia of the total pressure)?

Solution: The saturation pressure of steam at 100°F is 0.950 psia. Therefore, the relative humidity is 0.50 / 0.95 x 100% = 53%.

Superheated steam is steam that is at a temperature greater than the saturation temperature at the given partial pressure of the steam, or equivalently at a partial pressure below the saturation pressure at the given temperature. In the example above, at 53% humidity, the environment technically includes superheated steam since the partial pressure of the steam (0.5 psia) is below the saturation pressure at the given temperature (0.95 psia)! Similarly, subcooled liquid is at a temperature below the saturation temperature at the given total pressure (total pressure since the substance is in a liquid form). An example of a subcooled liquid is a glass of water which is evaporating.

A relative humidity of 100% implies that the environment includes saturated steam, although at low temperatures, it is usually not thought of as such. The reason is that at low temperatures and 100% humidity, the amount of moisture is much less than at higher temperatures. The absolute amount of moisture is directly related to the partial pressure of the vapor and the probability of condensation is related to the partial pressure of the vapor and the temperature of the surface where the moisture might condense. Condensation occurs if the partial pressure of the vapor is above the saturation pressure corresponding to the temperature of the potential condensation surface.

Example: Will condensation occur from a water vapor/air mixture at 150°F and 40% humidity onto a surface at 100°F?

Solution: The partial pressure of the water vapor is the relative humidity in decimal form times the saturation pressure of steam at 150°F, or 0.40 x 3.722 = 1.5 psia. The saturation pressure corresponding to the temperature of the potential condensing surface is 0.95 psia. Therefore, condensation will occur.

The theoretical sequence of events which occurs to a component when steam is dumped into a closed compartment (such as a containment) is as follows. First, the component is usually at a temperature below the saturation temperature corresponding to the resulting partial pressure of the steam (unless the component has very significant self-heating). Condensation immediately begins on the surface of the component. The maximum temperature of this condensed steam is the saturation temperature of steam at the partial pressure of the ambient steam. Next, as condensation continues and heat is transferred to the component from the ambient steam, the temperature of the component rises until it reaches at least the temperature of the environment. The temperature may increase further if the device generates any internal heat. Finally, at this point, one of two situations occurs: if the device has self heating, it will eventually cause the collected moisture to evaporate; if not, an equilibrium will be attained with liquid on the device in equilibrium with the surrounding environment.

In reality, the sequence will not occur exactly as described above. Many interacting factors will govern exactly what happens. Some important complicating effects are those of chemical sprays and contamination in the plant (dust, chemical residues, rust, etc.) which will tend to keep more moisture on equipment.

Hopefully, the above will provide some insights into what a "steam" environment really is and some of the very basic mechanisms of steam behavior.

Post-Accident

The regulations generally require that equipment be qualified for the time duration that they need to function, plus margin. The staff position has been that post-accident acceleration using Arrhenius analysis is normally acceptable as long as the acceleration is not excessive (not easily defined, of course). The DOR Guidelines tend to be most permissive in that they only require qualification up until the time that the accident conditions have essentially returned to pre-accident values, and they also specifically allow thermal aging-type calculations to justify even shorter tests.

Even though the post-accident acceleration has typically been deemed acceptable, there are some assumptions made in the analysis that are significant and may be non-conservative in some cases. One example is that using thermal aging analysis for post-accident qualification assumes that the only failure mechanism is thermal age related. This approach discounts long-term moisture related failures to a large extent, should they exist.

In general, the transient part of the accident may not be accelerated or used for acceleration; only the steady state portion of the post-accident exposure should be accelerated. However, calculations which include credit for the transient portion of the accident and demonstrate very long post-accident qualification are generally not questioned (i.e. where the steady state portion alone could easily be shown to be sufficient by itself).

Submergence

The regulations all support actual submergence testing to qualify components which may become submerged. Specifying saturated steam during accident testing is generally not considered adequate for submergence qualification.

Example: A clear case where saturated steam would be insufficient is when testing terminal blocks. For many applications, the blocks can be qualified for saturated steam, but invariably, terminal blocks will fail when submerged.

From a technical standpoint, it should be possible to qualify some types of equipment for submergence based on saturated steam testing. Specifically, the following points would need to be addressed:

--The device would have to be sealed from the environment by design.
--The qualification report would have to make a clear and convincing argument that no moisture got into the device. A simple visual inspection stating that there was no evidence of moisture intrusion may not be sufficient, although ~~detailed~~ examination results might be more convincing.
--Similar to the above, a valid argument addressing moisture intrusion from interconnections, such as cables, conduit seals, and conduit fittings, would be necessary.
--Verification that the seal materials would not be degraded by the submerged condition.
-- Pressure

Examples for discussion:

1) Minco RTDs submergence question at Diablo Canyon.

2) Neutron monitor junction box at Maine Yankee

Functional Performance Requirements and Data

The regulations require demonstration that plant functional performance requirements have been satisfied for the environments in which the device must operate. Many individual instances can be cited where utilities have failed to do this, but they generally fall into one of two categories:

1. The functional performance requirements are not specified adequately.
2. The qualification report and EQ file do not demonstrate that the functional performance requirements have been met, most often during accident conditions.

The first item seems obvious, yet legitimate questions can be asked such as what are the necessary functional performance requirements for a section of cable, which doesn't necessarily have an easy answer. Even further, what is the necessary accuracy for a pressure transmitter used to monitor reactor coolant pressure following an accident and what is the technical basis to support the necessary accuracy? In general, the accuracies should be based on assumptions used in developing the plant safety analysis, but determining the necessary accuracy for a particular instrument is often difficult on this basis.

Let's leave some space here for notes and get some class opinions on the subject of determining instrument accuracy.

Inst Accuracy ± 2% normal Ops
± 10% during ~~accident~~ accident
as determined during test.
Licensee has to address why
± 10% is acceptable for
accident - Difference from T.S

In general, power and control devices have somewhat more easily specified performance requirements. For example, a motor operated valve may need to "open or close on demand and remain in the desired position." However, one might ask the following question of a particular test which appeared to demonstrate the above capability:

--Does the motor torque degrade during the accident test? If so how much, and does this degrade operability of the valve in the as installed configuration (e.g. when working fluid interactions with the valve are considered, coupled with degraded torque).

As another example, a solenoid valve might have similar requirements as for the motor operated valve described above. However, one might fail to consider a specification on allowable leakage of the valve. How to determine the allowable leakage may be somewhat difficult, but it should be addressed.

Utilities generally use two different approaches to determine the functional performance requirements. First, based on something, they may determine the necessary requirements for their application and then check that a particular test verifies that the requirements are met. Alternatively, the demonstrated parameters from testing may be evaluated and found to be acceptable. This second method presents somewhat of a direct conflict with IEEE 323-1974, which states in section 6.3.1.1 that the test plan should include "(9) Performance limits or failure definition." However, the staff position has been to accept this latter method of demonstrating functional performance, largely because much testing is done in a generic fashion and in most cases, the functional performance requirements are plant specific.

Interconnecting devices, such as cables, penetrations, terminal blocks, etc. present unique challenges to defining functional performance requirements. What is it that these interconnecting devices must do, exactly? They must transmit current and voltage from one place to another while maintaining the desired characteristics of the transmitted parameters. The first part, that of transmitting current and voltage from one place to another, is usually addressed in any reasonable qualification. The second part is the difficult part. What parameters need to be measured to determine that the desired characteristics of the transmitted current and voltage are maintained? At this point I will defer further discussion to the specific issues sections.

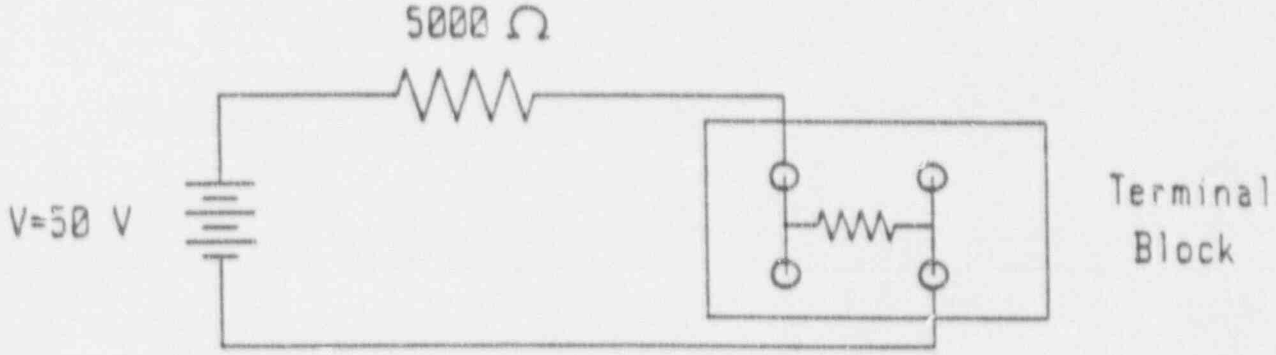
Once adequate and complete functional performance requirements are defined, the second step is to demonstrate that they are met based on the tests conducted. It is easy to envision that the most important time, and indeed, often the most difficult time, for verifying functional performance requirements is during accident environment application. The specimen will usually be inside a test chamber where it is largely inaccessible and the harsh chamber environment makes some types of monitoring difficult. If a good test was conducted and all the pertinent parameters were measured, it is straightforward to compare the specifications to the demonstrated performance. In many cases, however, the performance data during the accident test is not 100% complete. The following give some examples of potentially incomplete data:

--All parameters were not measured during the accident exposure.
--Parameters were not measured at appropriate times.
--The data presented is inconsistent and thus questionable.
--Parameters were not measure over the entire spectrum of instrument operation.
--At the utility level, the test report may not include all data that was taken during the test.

Thus, it is often necessary to use good engineering judgement, experience from similar tests, and insights from other team members to make a determination as to whether the performance requirements have been adequately satisfied.

The individual sections on specific components will provide more insights for component specific functional performance requirements.

Later, we will discuss the related measurements of insulation resistance (IR) and leakage currents. At this point, we will address the question of the relationship between IR and leakage current. In Ohm's law, V = I * R, the resistance R (or IR) is assumed to be a fixed value, as for a commercial resistor. On the other hand, leakage current I is directly proportional to applied voltage (with R assumed constant). The applied voltage is the voltage across the resistance R and may vary with varying leakage currents. In the figure below, the voltage applied to the circuit is 50 Vdc. With no leakage current (i.e. R=∞), the voltage applied across R is 50 V, but with a leakage current in the circuit of 9 mA, the voltage applied across R is only 5 V. The corresponding leakage current if the full 50 V were applied would be 90 mA, a significant difference. Thus, it is important to remember that leakage current varies with voltage, but resistance is generally assumed to be independent of voltage. It should be mentioned that some valid arguments do exist to refute that R is independent of voltage, but we will not discuss them here.



Similarity

All the regulations require that qualification be based on either an identical or similar piece of equipment. If qualification is based on a similar piece of equipment, then a supporting analysis is necessary to demonstrate that the tested and installed equipment is indeed similar. This is often necessary since every different model, configuration, and installation cannot be tested practically. Therefore, we have the question, what constitutes a similar piece of equipment? The answer, as so many times before, is not an easy one. Similarity may need consideration of form, fit, function, materials, manufacture, and installation. A very important point is that similarity depends largely on the application. A similarity argument essentially must demonstrate that because one piece of equipment was successfully tested in some environment, another piece of different equipment will also perform its required function in another (possibly different) environment. Consider some examples as follows:

> A pressure transmitter with a range of 0-1000 psi is to be qualified based on testing of a pressure transmitter with a 0-10 psi range. Everything is identical about the transmitters except that a different stainless steel bellows is used. The desired qualification environment is the same as the test environment. Are the units similar?

> A limit switch was tested using a conduit seal to IEEE 323-1974 conditions (including 200 MR radiation). A plant is using the same limit switch in a radiation only harsh environment (100 MR maximum), but they did not install a conduit seal. Is the tested switch similar to the installed switch?

A whole family of cables is to be qualified based on testing of representative samples. Which cables should be chosen as the representative samples? See Table 1 in IEEE 383-1974 for suggested selection of representative samples. In addition, paragraph 1.3 states that "qualification of one cable may permit extrapolation of results to qualify other cables of the same type, with consideration given to cable dimensions and probable modes of failure."

A terminal block from one manufacturer is to be qualified based on testing done on the terminal blocks of two other manufacturers. All are made of a nonspecific phenolic material. The testing on the two terminal blocks used the IEEE 323-1974 suggested profile (340°F for six hours, etc.). The terminal block to be qualified is used where the peak environment is 225°F for 4 minutes, followed by a decrease to 150°F in 30 minutes and return to the ambient of 90°F after 3 hours. Performance of the tested terminal blocks was quite good, about as expected for terminal blocks in the test environment. Are the blocks similar?

More similarity examples, including discussion of generic materials similarity, will be included in the specific component sections.

Margin

Margin is essentially the difference between the worst case plant conditions and the test conditions. It is applied to account for uncertainties in the qualification process and for normal production variations of equipment. IEEE 323-1974 gives recommended values for margin and they will not be repeated here. A significant point to address here is that of margin in one area "compensating" for lack of margin in another area or in some cases, even lack of enveloping in some areas. My philosophy is that one needs to look at the qualification package as a whole and decide whether the package verifies with reasonable certainty that the equipment will perform its function when required. Thus, my feeling is that some amount of the above is reasonable. However, some points I would carefully consider are as follows:

--A great deal of margin in one area should be used to get a much smaller margin in another area.
--The area lacking some margin or enveloping should be an area where known failure modes of the type of equipment under consideration are not dominant.
--Knowledge of industry qualification experience with the equipment neede to be considered.
--When in doubt, consult with others as appropriate, and when not reasonably sure, err on the conservative side.

Some examples:

--A cable was tested to a demineralized water environment when it is needed in the plant for a more severe chemical spray environment. A successful argument might be that the other parameters are well enveloped, the material the cable is made of is not typically degraded by the chemicals in the spray, and that cable failures in qualification testing are normally unrelated to chemical sprays.

--A solenoid valve was tested to a 300°F/67 psia saturated steam environment for 3 hours and is needed at 320°F/50 psia superheated steam environment for 30 minutes, followed by 30 minutes at 275°F. The above requirements include the suggested 15°F margin. The solenoid valve was thermally aged at 350°F for 7 days prior to steam testing. A successful argument be that the valve was aged at a temperature well above the necessary steam qualification, that there is significant time margin in the test (even though at a reduced temperature level), that the required pressure was enveloped, that the actual required temperature (before margin) is only 5°F above the test temperature, that the actual amount of moisture present is enveloped, and that the temperature/moisture interaction in the steam environment is not a major failure mode for solenoid valves. A similar argument might not work so well if the component were a terminal block used in an instrumentation circuit.

Specific Component Issues

Cables

The following list includes many of the issues identified for cables:

--Utility does not know for sure what cable is installed.
--Utility does not have all installed cable on the master list.
--Utility does not have adequate documentation for qualification.
--Similarity inadequate (includes generic qualification issues).
--Functional performance inadequately addressed.
--Environments not enveloped.

The first two items on the list are related and may be assessed in two major ways. One way to assess what is installed vs. what is on the master list is to look at cable in the plant that is connected to qualified equipment and verify that the cable is on the master list (physical inspection covered elsewhere in the course). In some cases, the cable may not be field identifiable and it is necessary to rely on the second method, examining the plant's quality assurance and installation records to identify cables. In some cases, utilities do not know exactly what cable is installed in what circuits, but they do have an exhaustive list of all cables which might be installed in qualified circuits and they have qualification documentation for all the possibilities. Obviously, this is the less preferable method since any problems identified with a particular cable (either during an inspection or at a future time) are much more difficult to deal with.

The remainder of the list looks very familiar to the items in the earlier definition of qualification given earlier. Cable similarity has been questioned often and in many cases has not been adequately demonstrated. Recently manufactured cable is much less prone to similarity problems because the industry has become well aware of the issues involved. The major problems thus occur with older cables. One of the more controversial issues has been that of generic material qualification, i.e. trying to qualify one manufacturer's cable based on successful testing of a second manufacturer's cable made of the "same" material. In some cases, generic qualification has been accepted to a limited extent, but this hardly means that the staff position is to accept it blindly as some in industry, particularly consultants, might imply. Each case must be carefully evaluated on its own merits. I will attempt to give some insights into what needs to be considered in such a qualification because each case is unique. The following questions should be kept in mind during a review:

Generic Qualification

--Is the cable inside or outside containment?

cable rating might be considered

--What are the environmental conditions for the cable?
--What are the typical capabilities of the material under consideration?
--How does the local environment compare with typical capabilities of cables in general as well as with typical capabilities of the particular material?
--What similarity information is available for the tested vs. installed cables?
--What type test data is available for the specific material?
--How much can margin in one area compensate for deficiency in another area?

Cable Samples IEEE 383/74

So far, only one instance of generic material qualification for inside containment applications (Ft. St. Vrain) has been accepted, based on special circumstances including virtually no radiation dose and a relatively short accident environment at high temperatures. Several additional cases have been accepted for outside containment based on considerations of the above. The above type of information should be addressed in the qualification package. As is apparent, determining the adequacy of generic qualification can require experience and good engineering judgement. When in doubt, consult with others as necessary.

Many other similarity issues have come up. In general, the utility should have a certificate of conformance from the manufacturer with a statement that the cables are identical or similar to tested cables. If similarity is claimed, the basis should be specified and justified, as necessary. An earlier example gave information on choosing representative samples from a family of cables. Thus, a statement from the manufacturer that the materials and method of construction are the same as tested cable is generally sufficient for establishing similarity unless particular concerns are known for the specific cables. The testing should generally include samples with the minimum thickness of insulation used in the plant. Most recent qualifications will meet these criteria.

Example for discussion: Butyl Rubber. Both Big Rock Point and Quad Cities have butyl rubber cable installed. Both qualifications have been questioned for various reasons.

Discussion:

Some difficulty may arise in terminology such as if a utility states, for example, that they have Rockbestos Firewall III insulated cable and that testing was also performed on Rockbestos Firewall III insulated cable. In fact, much more specific information is sometimes necessary to establish similarity. Some information will be given in the specific product listing for commonly encountered cable products; in other cases it may be necessary to request vendor catalog information, discuss specifics with the licensee, or consult with appropriate personnel.

The question of adequately addressing functional performance for interconnecting devices was mentioned earlier. The staff position for cables has been different for different types of cable. For instrumentation cables and interconnections, the primary parameter of interest is IR data or leakage current data during the steam/spray simulation. The concern is greatest for devices involving exposed terminals of any kind, such as terminal blocks. However, the staff position has been to require data for any instrumentation interconnecting device exposed to harsh steam environments. Analysis of the effects of degraded IR on instrumentation circuit accuracies has often been neglected by utilities in the past. Two methods may be used to assess the effects: either determine an acceptable IR for the circuits and verify that it is met or verify that the measured values are adequate. The individual sections on specific components will describe the types of analysis for determining potential accuracy degradation from interconnecting devices. In general, for non-coaxial type applications, instrument cable IR of above $10^6 \Omega$ for a test length of 10-15 ft can be shown to be acceptable. Coaxial cable applications have special requirements and will be discussed in the radiation monitor section. The major application for coaxial cable inside containment, other than radiation monitors, is acoustic monitors for valve position indication. Specific requirements for these circuits don't seem to be nearly as severe as for radiation monitors, but they have never been as extensively examined; they will not be covered in this material.

Power cable is at the opposite end of applications from instrument cable. The staff position has been that IR measurements are not necessary for power cables if a good test was performed and the cables were loaded with appropriate current and voltage during the test and satisfactorily passed a post-test dielectric withstand test. (In some older qualification tests, the withstand test may not be included.)

Control cable applications, and hence requirements, fall somewhere between power and instrumentation. In some control circuits, IR considerations may become important, although this is rarely the case. Cable IRs above $10^5 \Omega$ for a test length of 10-15 ft during steam testing are generally sufficient. For most outside containment applications, the IR for control cables would not fall to low enough values to cause circuit problems. Hence, in some cases, a test where IRs were not measured has been found acceptable if a good test was performed and the cables were loaded with appropriate current and voltage during the test and satisfactorily passed a post-test dielectric withstand test. For inside containment applications, the IR data would generally be required. In any case, consideration of the environment the cable is expected to survive in is an important consideration.

Several specific areas to be aware of are as follows:

--Scaling of IR data. According to physical laws, if the cable length is increased, its IR decreases. A few manufacturers report IR data using units of Ω-1000 ft, which is the IR of 1000 ft of cable. Most report the IR for the tested length of cable. It is important to recognize that the two may easily differ by nearly two orders of magnitude and that the guidelines mentioned in the above paragraphs refer to tested lengths of cable. In analyzing the effects of degraded IR, the actual installed cable length needs to be considered relative to the tested length. The IR to use in the calculation is found by as $IR_{installed} = IR_{tested} \times$ (length tested / length installed). If the IR is given in an Ω-1000 ft basis, then 1000 ft should be used as the length tested. In actual testing, the measured IR is artificially low because of the parallel effects of penetrations and lead wires. Sandia has data over a limited range which appears to support an increase in a calculated value by at least a factor of 2 if the scaling is over a length of at least a factor of 3.

Example: A 15 ft section of cable was tested and had a minimum IR of 5×10^5 Ω. The plant has an installed length of 200 ft. What IR should be used in the circuit calculations?

Solution: The IR equation gives $5 \times 10^5 \times (15 / 200) =$ 37.5 kΩ. However, the length scaling is greater than a factor of 3; thus, the IR may be increased by a factor of 2 to 75 kΩ.

--Failure modes considered. In some cases the utility may only consider certain failures resulting from decreased IR. One common occurrence in consideration of control circuits is to only determine if the IR is low enough to cause fuses to open. In fact, there may be other undesired effects which can occur at much higher IR than that required to open a fuse, such as spurious indication or operation. Some of these will be discussed in other sections.

--Use of post-test IR data in analyses. Where IR considerations are important, it is imperative that IR data during steam/spray exposure be used. The IR almost always recovers after removal of the harsh environment (unless a failure has occurred).

--A rule of thumb is that bulk IR decreases by a factor of 2 for every 10°C increase in temperature when in a thermal-only environment. Decreases at least that large should be expected during steam testing, with higher values possible. This rule may often be used as a basis to assess whether test results are reasonable.

The following list gives some manufacturer's product names along with some information about the product.

--Rockbestos Firewall III and Pyrotrol are product names for chemically cross-linked polyethylene (XLPE) insulation and may use either a hypalon or a neoprene jacket. Pyrotrol is an old formulation; Firewall III has been produced since Pyrotrol and has several different formulations, most with a KXL 760 type designation (one old formulation is KXL 510). The most recent formulation is KXL 760D and is covered by Rockbestos test report QR-5804 (a new report of testing which the NRC closely followed). Most older formulations are qualified by utilities using old test reports (those questioned in IN 84-44) in combination with similarity to tested KXL 760D and possibly other test reports. IN 84-44 allows several methods for dealing with the old questionable test reports including performing additional testing, analyzing the old test reports (to show significant margin to account for possible problems), or obtaining additional test reports from other sources (some Sandia testing has been cited). The Firewall III designation is also used for irradiation XLPE; however, the formulation of irradiation XLPE has not changed over the years to the best of our knowledge. A new test report, QR-5805, covers all irradiation XLPE and this testing was also followed by the NRC.

--Rockbestos Adverse Service Coaxial Cables are available in several different products, the most common being RSS-6-104 and RSS-6-113. These use two insulations, a radiation XLPE insulation and a inner insulation, called either LD or LE. The original (1st generation) coaxial cable was found to not function satisfactorily above about 230°F and is supposed to have been removed from all applications where the temperature could exceed the thermal limitations. The 2nd generation cable used a modified braid angle to prevent the conductor kinking failures of the 1st generation cable. Subsequently, the LD polymer of the 1st and 2nd generation cable was changed to an LE polymer and the new cable is designated 3rd generation. The LE formulations were tested successfully and the results are reported in QR-6802. A similarity analysis was prepared by Rockbestos to qualify the 2nd generation cable based on the 3rd generation cables (the 2nd generation test report is one questioned by IN 84-44). This analysis has been reviewed by the staff and has been accepted at several plants. Production dates for the cables are as follows: 1st generation before 6/8/81, 2nd generation from 8/20/81 to 3/14/83, and 3rd generation since 3/15/83.

--Rockbestos also produces silicone rubber (SR) and ethylene propylene rubber (EPR) insulated cables which have not been retested. Qualification depends on plant specific applications and analysis within the guidelines of IN 84-44.

--General Electric SI-57279 is called Vulkene Supreme SIS and is a XLPE insulated cable. One applicable test report is #F-C4497-2, a Franklin report of 3/77. A letter recently seen at a utility indicated that GE considers standard Vulkene SIS, or SI-57275, to be not qualified. Thus, it is important to distinguish between the two, non-similar formulations. The SI-57275 may possibly be qualified by other test reports to some environments, but GE currently sells only the Vulkene Supreme for nuclear applications. A current question under investigation is what Vulkene cable is used in GE electrical penetrations produced a number of years ago.

--Boston Insulated Wire (BIW) Bostrad 7E cable is an ethylene propylene rubber (EPR) insulated and hypalon jacketed product. Qualification testing is covered by BIW report BIW 915 and an updated version BIW 915A. Both of these reports have been determined to not support IEEE 323-1974 qualification. See Inspection report 99900283/83-02 for more details. This test report has been found acceptable for some applications where the DOR Guidelines apply. Current information indicates that additional testing of the cables has been performed to qualify them to 10CFR50.49 requirements.

--Samuel Moore (Eaton Corp.) Dekorad is an ethylene propylene diene monomer (EPDM)/hypalon layered insulation with a hypalon jacket for instrument applications. Cable testing is reported in an Isomedix test report of June, 1978. Other Samuel Moore cables include Polyset (radiation XLPO) and Elastoset (Flame Retardant EPDM).

--Kerite Corporation high temperature (HT) or high temperature Kerite (HTK) and a flame retardant (FR) compound are used in various combinations for insulations and jackets for power and control cable. Various combinations have been tested, with the control cable giving low IR values.

--Brand Rex produces a XLPE insulated cable with a hypalon jacket. Testing is reported in Franklin Reports series F-C5120- and in report F-C4113 for various applications, configuration, and types of cables.

--Raychem Flamtrol uses an XLPE insulation and has not been produced for quite some time. It is used at a number of plants and qualification should always be to the DOR Guidelines.

--Okonite has a number of different products, including insulations/jackets with trade names Okonite (EPR), Okoseal (PVC), Okoguard (EPR), Okozel (modified ethylene tetrafluoroethylene, or tefzel), Okotherm (SR), Okolon (EPR/hypalon composite), and X-Olene-FMR (chemically XLPE). Okonite did research testing on many products and supplies selected data to customers based on individual needs. Some concern has been noted that only positive results have been given to customers, with no mention of test anomalies or failures on similar or identical cables. The large number of different cable materials indicates that care should be used to ensure similarity of test specimens to installed cables.

A large number of cable types have been identified at only one or two utilities and hence must be carefully evaluated on a case by case basis. The following list gives some of these rare manufacturers/types (for nuclear use), but no attempt is made at describing any in detail:

BIW silicone rubber, Galite, Hatfield, Lewis, Simplex, Plastics Wire and Cable Co., Essex, Times W&L, Rome (Cypress), Tensolite, General, Teledyne, Haveg, Essex, and Harbour.

Some of the above may include manufacturers that are subsidiaries of more common manufacturers or names that have otherwise been obscured.

Some more common manufacturers have had name changes or affiliations which are useful to know. For example, Rockbestos was formerly called Cerro, Continental is a subsidiary of Anaconda, and Rome and Cypress are equivalent.

GE Vulkene Supreme — is qualified
~~GE Vulkene — is not qualified~~
GE Vulkene
There is a difference + need to be applied appropriately

Electrical Penetration Assemblies (EPA)

As for any other type of equipment, the problems for EPAs fall into categories of similarity, performance requirements, and environmental enveloping. However, concerns over similarity and environmental enveloping have been much less pronounced than for cables. Functional performance has very often been neglected for EPAs, but the required analysis is exactly the same as for cables, terminal blocks, etc. with the EPA simply another parallel resistance in electrical circuits. Since component specific IR effects will be discussed separately for different devices, they will not be repeated here.

The most significant recent similarity issue has been that of butt splices supplied by GE with F-01 series electrical penetrations. As a result of audit findings at Dresden, CECo tested splices at Wyle and found some failed the test. The original issue stemmed from GE supplying nylon-insulated splices from more than one manufacturer, with no specific documentation to establish exactly what was tested nor what was supplied to plants. It should be noted that CECo believes that the connectors are still qualifiable and that the configuration in the Wyle test was overly conservative. Butt splices that were taped successfully passed the qualification test and CECo has taped the splices in both Dresden and Quad Cities.

One concern that has been identified as a result of Sandia testing is that electrical failures of D. G. O'Brien penetrations may occur as a result of moisture intrusion. The moisture barrier, made from a silicone rubber elastomer, tends to undergo major dimensional changes when subjected to compressive loads, especially when also subjected to elevated temperatures. These changes have been observed to cause damage to conductor insulation as well as allowing moisture intrusion. One way to avoid the failures may be to age component parts separately, but separate aging may not be realistic. Consequently, D. G. O'Brien EPAs should be examined carefully.

IN 84-47

Terminal Blocks

The generic issues for terminal blocks parallel those for other equipment. In general, I feel that dimensional differences, including the shape of the block and the shapes of convoluted surfaces on the block, are the major factor governing differences in terminal block performance. The major factor for terminal block performance is the ability to carry voltage and current without excessive leakage currents. The major mechanism for terminal block failure in a steam/chemical spray environment is surface leakage currents and/or surface breakdown. The major factor governing the leakage currents seems to be the physical size and detailed shape of the block. This information suggests that the materials of construction have less effect on accident performance than for other types of equipment, as long as severe radiation or thermal degradation has not occurred. In general, phenolics are used for terminal block construction and they are not very age sensitive. Consequently, the major emphasis should be on accident performance. Similarity evaluation should largely be based on dimensional considerations which lead to primary failure modes.

One particular block which has received considerable attention lately is the Marathon 1500/1600 series blocks. The two series are quite similar and have been recently tested by Wyle for CECo to measure leakage currents. The leakage currents reached about 300 mA at 132 Vac and 135 Vdc for four terminal blocks (including a 1600 series) located below unsealed conduit entrances to the top of a NEMA-4 enclosure. The one block (1600 series) not located below the top entrances gave leakage currents below 40 mA at similar voltages. The obvious conclusion is that any top entry conduit usage should be examined carefully and generally discouraged.

The Wyle test has a very subtle, but instructive example of possible improper monitoring of leakage currents in any test. In the figure on the next page, the value of P1 is adjusted to give a loop current of 16 mA during the accident simulation. A simple calculation giver the required value of P1 as 625 Ω. Another simple calculation, assuming a dead short of the terminal block for circuit 1, gives a loop current of 67.2 mA as the maximum loop current. The 500 mA fuse included in this loop can never open as a result of leakage currents on the terminal block! Fortunately, in this test actual leakage currents were monitored. However, if the actual leakage currents had not been monitored, this particular circuit would give no indication whatsoever as to terminal block leakage currents during the accident exposure. This example emphasizes the need to see accurate and complete documentation of test apparatus, particularly when leakage currents are claimed to be monitored via a fuse in the energizing circuit.

In another Wyle test (45603-1) of the same terminal blocks, when power was applied to test specimens following a power

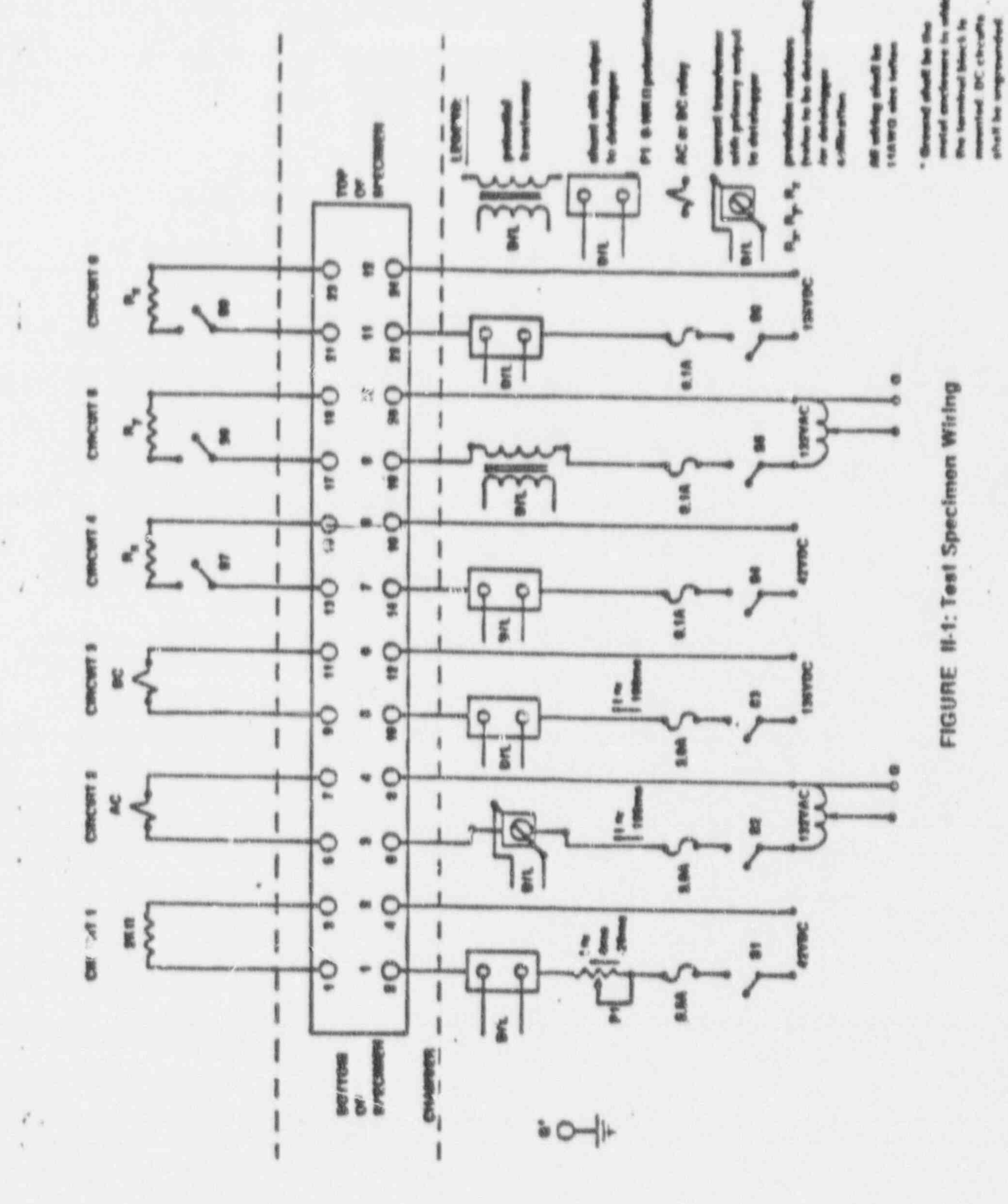


FIGURE II-1: Test Specimen Wiring

outage, the fuses connected to the terminal blocks all opened. In the test, 132 Vac circuits used 12 A fuses, 264 Vac circuits used 18 A fuses, and 528 Vac circuits used 24 A fuses. At other times, the 264 Vac and 528 Vac circuits had fuses open. The conclusion from the tests was that the blocks were not suitable for use in 528 Vac circuits when exposed to the conditions of the test. The opening of the fuses after the power outage was attributed to a test anomaly. However, in some plant applications, the same type of sudden powering may occur, raising the question of whether similar high transient leakage currents could occur in plant applications. The results from the Sandia tests showed the same kind of behavior when voltage was suddenly applied.

Figure 30 gives an indication of the variation of terminal block IR with voltage and temperature noted in Sandia testing. The applied voltage up to 100 hr was 45 Vdc. Note that the steady state IR is lower at the lower voltage and that the IR decreased substantially when power was suddenly applied even though the temperature had decreased. Figures 56 and 57 give additional data which indicates that for terminal blocks, the IR as a function of voltage is difficult to generalize over the small voltage range tested. A theoretical model developed for steady state conditions suggests that IR is constant up to a certain voltage (depending on specific parameters of the moisture film and terminal block), followed by increased IR at higher voltage as the moisture film dries out Transient conditions are much more difficult to predict, but the experimental data provides two insights consistent with the steady state model: (1) when voltage is suddenly applied, a moisture film has had time to develop (no Joule heating to evaporate it) and the initial leakage current is high, followed by a reduction in leakage current over time as the leakage current heats and evaporates the film, and (2) when steam is first introduced into the environment, whether the block is energized or not, condensation occurs on the block fairly rapidly since the block is still at normal ambient temperature (see discussion of condensation under saturated vs. superheated steam). One final thing to note is that, based on the above discussion, superheated steam testing of terminal blocks is generally not adequate to simulate conditions which might actually be saturated.

Discussion of Limitorque Testing of Terminal Blocks

A Limitorque test (number B0119) was run to determine the suitability of various terminal blocks, including Marathon 1600 series, for use in motor power circuits inside motor operators. The test acceptance criteria was that the IR of unpowered blocks must remain higher than the IR of two powered blocks connected in series which were functionally verified to be capable of operating a motor. The philosophy of this test strategy has been questioned as well as the conclusion of

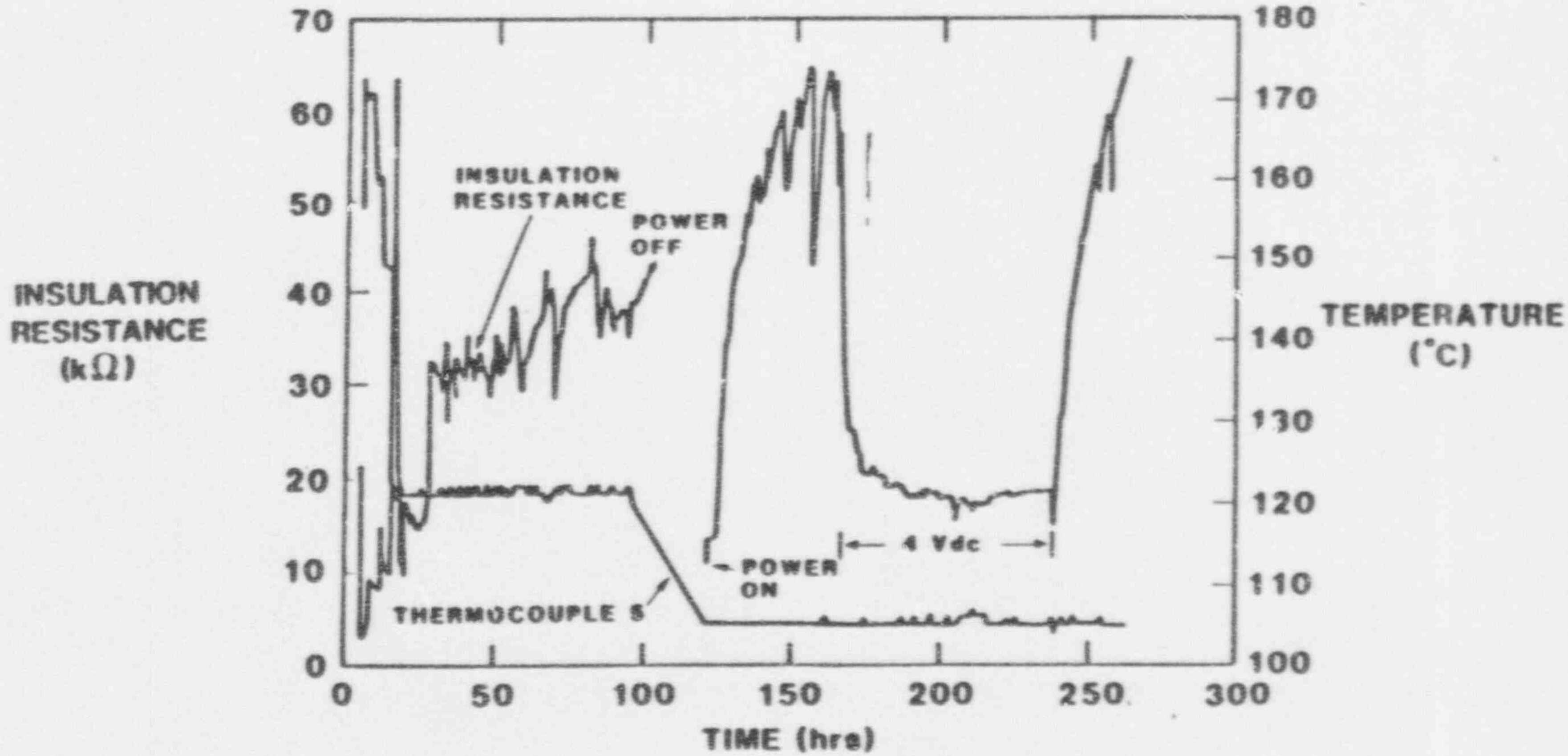


Figure 30

Insulation Resistance for Terminal Block 1 From the Second 172°C Plateau to End of Test. Temperature trace is for thermocouple 5.

Lower IR more Leakage Current

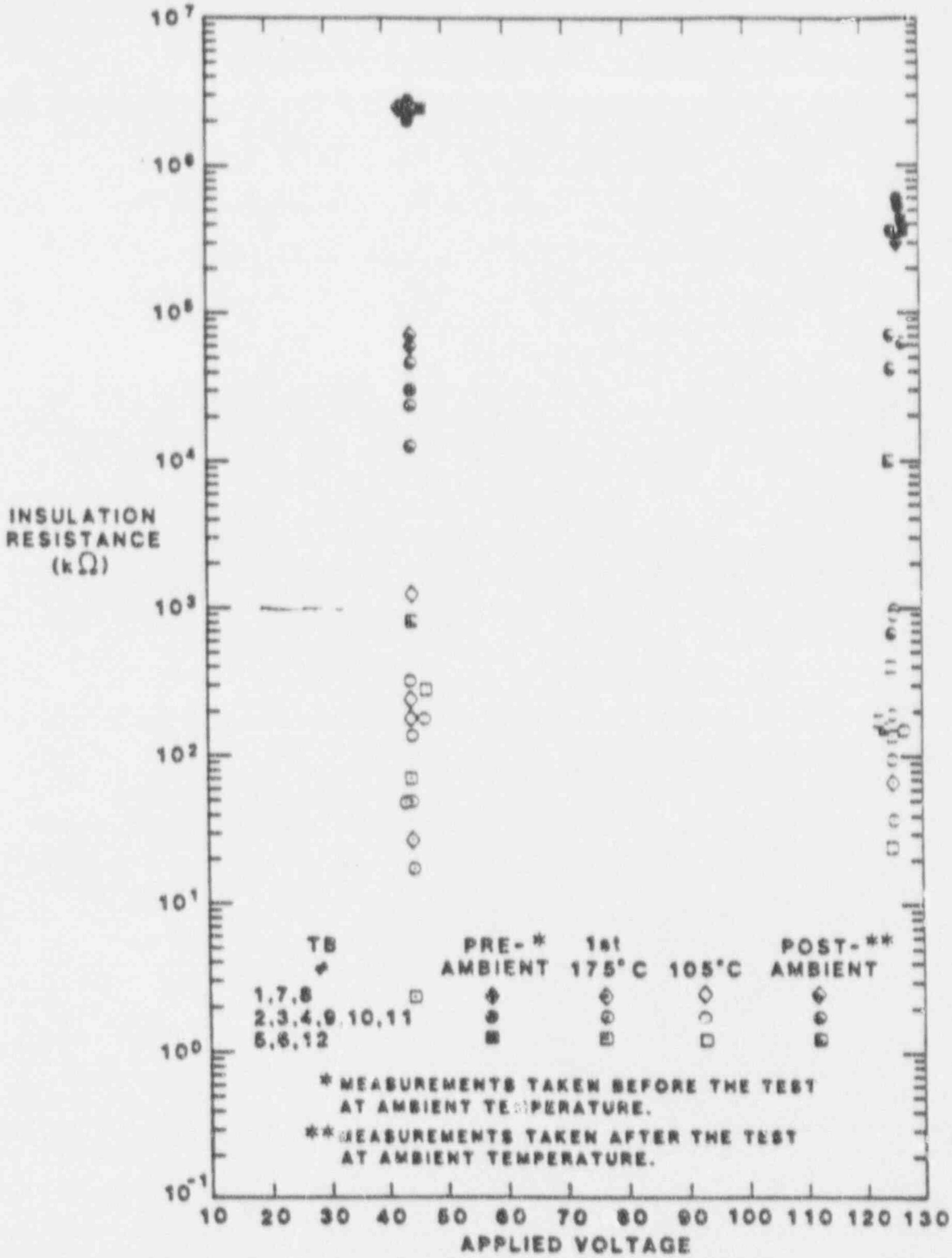


Figure 56

Insulation Resistance A for Pre-ambient, 175°C, 105°C, and Post-ambient Temperature Periods as a Function of Applied Voltage

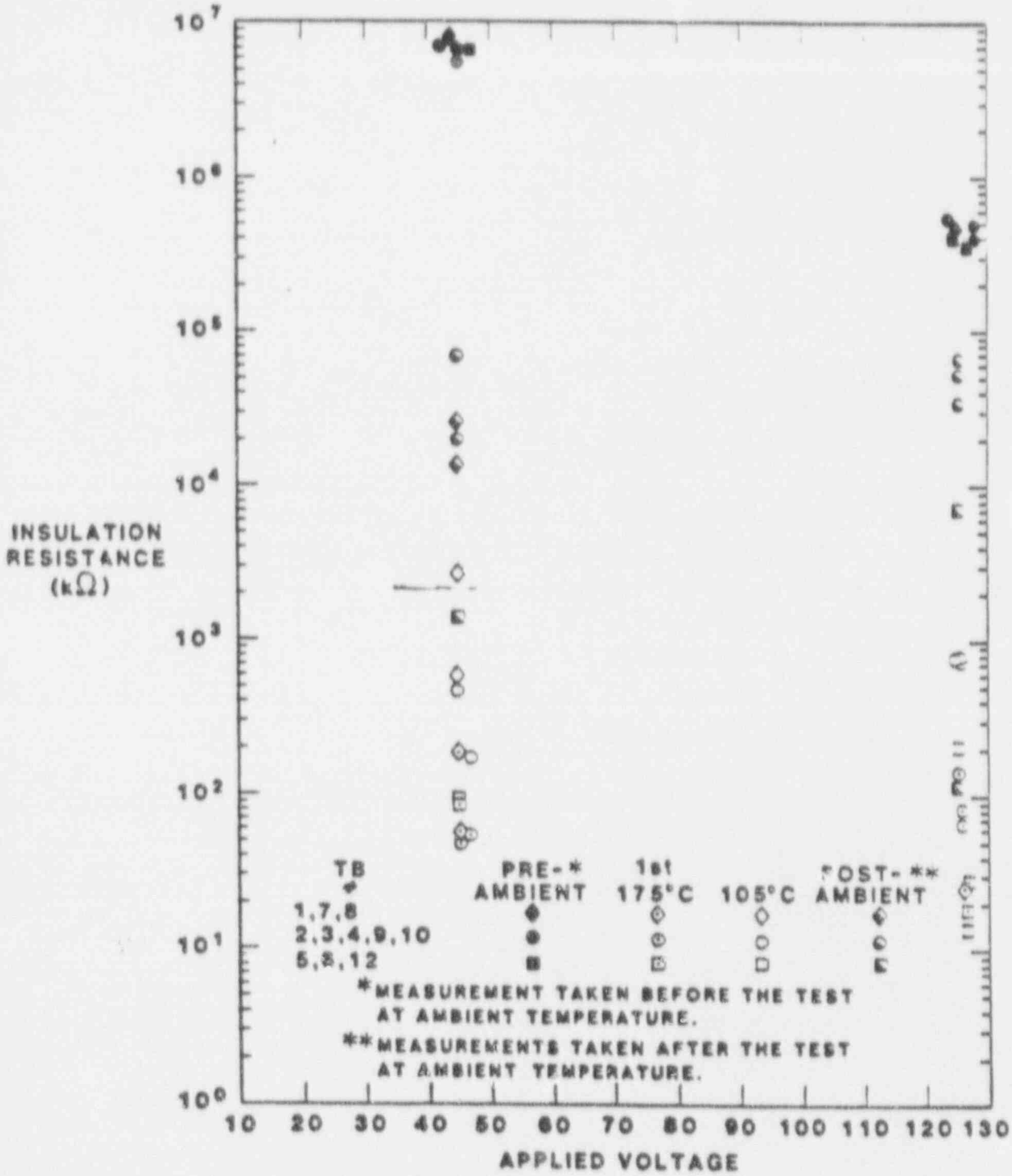


Figure 57

Insulation Resistance B for Pre-ambient, 175°C, 105°C, and Post-ambient Temperature Periods as a Function of Applied Voltage qualification from this test. Let's examine some positive and negative factors in this test:

Positive:

--Considering the discussion above, the unpowered terminal blocks may represent a worst case condition (i.e. maximum likelihood of film formation) with the IR measurements reading more typical of what might be expected in a plant before the motor operator is powered.

--Many tests of terminal blocks at lower voltages indicate that terminal block IR remains sufficiently high for power circuit applications.

--Power circuits are very insensitive to reduced IR of interconnecting devices.

--The test had two terminal blocks in series in the circuit powering the motor, essentially doubling the possible leakage currents.

--Terminal block measurements performed at low voltages may be more conservative than those performed at high voltages under steady state conditions since the higher voltage will drive the conducting film from the block.

Negative:

--The terminal blocks were not all powered during the test except during periodic IR measurements at fairly low voltages.

--The low voltage IR measurements give little direct indication of the terminal block performance at 480 Vac.

--The test strategy of using only IRs as an acceptance criterion is technically weak.

--The Wyle test of Marathon 1600 terminal blocks concluded that they should not be used in 480 Vac applications.

Discussion Notes:

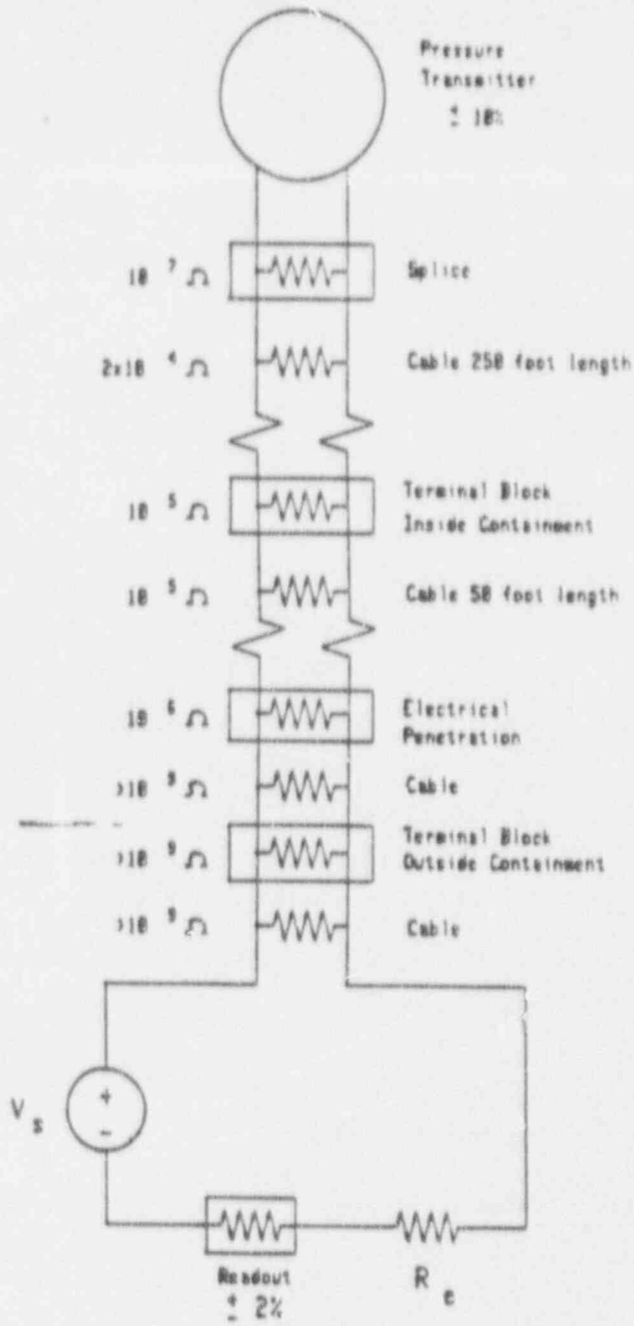
There are numerous additional blocks in use in plants with a partial list as follows:

Weidmuller SAK
States ZWM
Marathon 300/1500/1600
GE EB-5/EB-25/CR151
Curtis L
Amerace (Buchanan) NQB/0222/0524
Westinghouse 5224
Kulka -JJ

Most of the list covers a series of blocks with various numbers of terminals.

Testing by Sandia is reported primarily in NUREG/CR-3418 (data report) and NUREG/CR-3691 (assessment report). Some of the above statements are derived from insights gained during Sandia terminal block testing.

Probably the most significant issue for terminal blocks is that of functional performance requirements during accident testing. Ideally, terminal blocks and other interconnecting devices should be tested in circuits that are identical in every respect to what is installed in the plant. Some more recent terminal block tests have approached this goal by testing with representative loads on the terminal blocks. However, most testing has only been on the devices with some rated loading and possibly periodic leakage current or IR measurements. As with other interconnecting devices, terminal blocks constitute another parallel resistance in the electrical circuit. Individual component sections will discuss the effects of IR on the circuits.



Notes:

1. Pressure Transmitter compensates for for errors in V_s.
2. Cable shielding not shown.
3. All errors for accident conditions.
4. Assumes insulation resistance of $5x10^8 \Omega$ for a 10 foot cable section.
5. Effect of transmitter pigtail is included in transmitter accuracy.

Figure 1 Pressure Transmitter Circuit Showing Interconnections

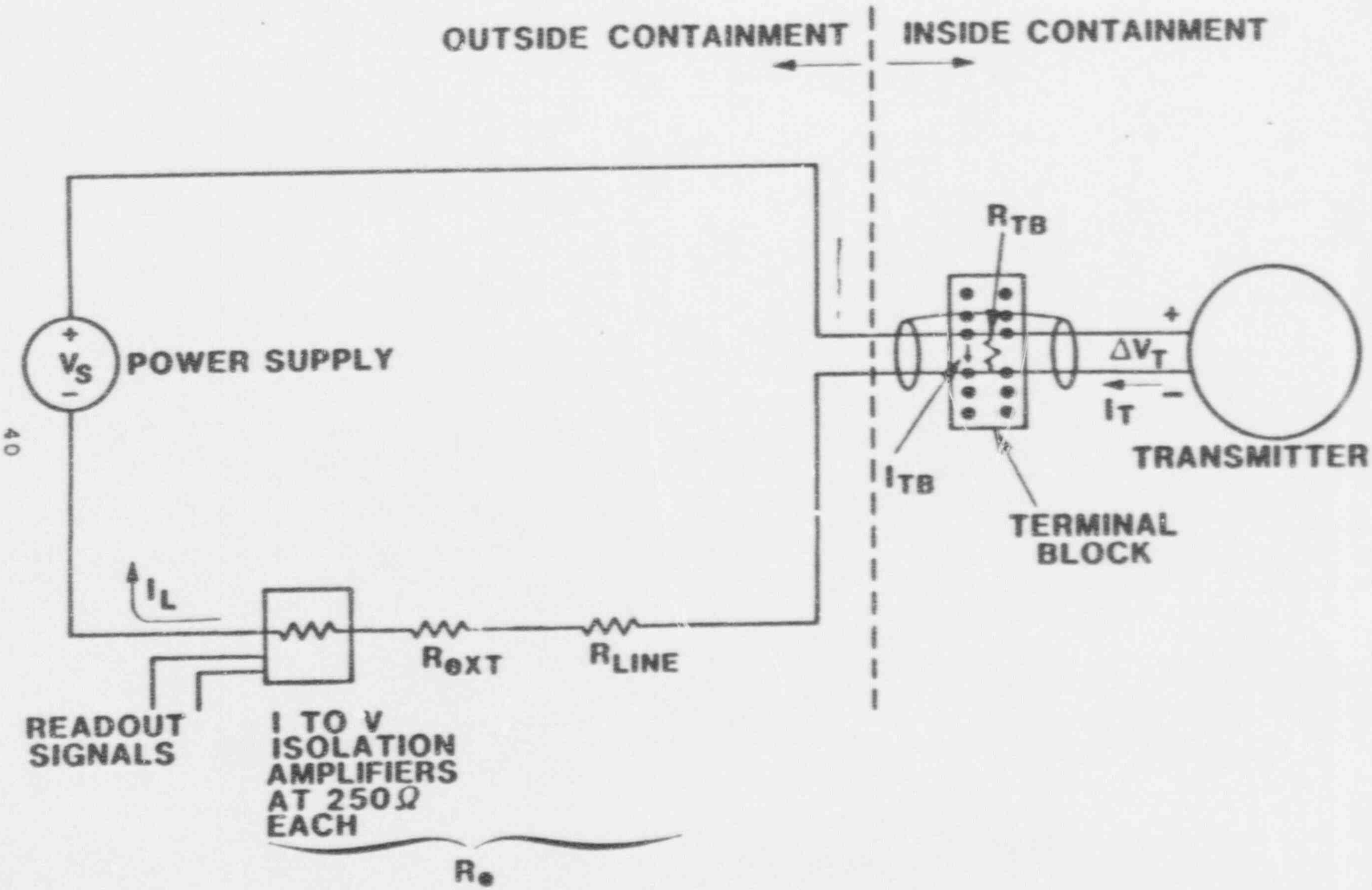


Figure 8-1: Simplified Schematic of a Typical Transmitter Circuit in a Nuclear Power Plant

The transmitter will operate correctly as long as the voltage remains in a specified range. For example, a typical transmitter will operate to specification as long as the voltage across the transmitter terminals remains between 15 and 50 Vdc. The loop resistance external to the transmitter (from the current-to-voltage amplifiers, the cable, and the other external resistances) also may vary over a specified range depending on the voltage supplied to the transmitter. For a typical transmitter, if the power supply voltage is '5 Vdc, the external loop resistance may vary between 250 and 1,500 ohms. Note from Figure 8-1 that the potential across the transmitter, ΔV_T, is essentially the potential across the terminal block and therefore would be the driving potential for any terminal block leakage current. ΔV_T can be expressed in terms of the normally constant power supply voltage, V_s, and the voltage drop, ΔV_e, across the external loop resistance, R_e:

$$\Delta V_T = V_s - \Delta V_e$$

$$\Delta V_T = V_s - R_e I_L \qquad \text{Eq. 8-1}$$

where I_L is the total loop current. The leakage current, I_{TB}, across the terminal block is:

$$I_{TB} = \frac{\Delta V_T}{R_{TB}}$$

where R_{TB} is the insulation resistance of the terminal block. The total loop current, which will be observed in the control room as the transmitter signal, will be the sum of the transmitter output current, I_T, and the terminal block leakage current:

$$I_L = I_{TB} + I_T \qquad \text{Eq 8-2}$$

Under normal conditions, I_{TB} will be zero or negligibly small compared to I_T. However, under accident conditions, I_{TB} can become a sizable fraction of I_T, and therefore, becomes a sizable portion of the total loop current sensed by control room instrumentation. The error, e, in the signal will simply be the ratio of the terminal block leakage current to the transmitter signal current. That is:

$$e = \frac{I_L - I_T}{I_T} = \frac{I_{TB}}{I_T} \qquad \text{Eq. 8-3}$$

Using the above equation, we can express e in terms of V_s, R_e, R_{TB}, and I_T:

$$e = \frac{V_s - R_e I_T}{I_T (R_{TB} + R_e)}$$ Eq. 8-4

This analysis gives error in terms of percent of reading. Typically, plants use percent of full scale when defining accuracy. To get error as a percent of full scale, simply substitute the full scale transmitter current for I_T in the denominator of Eq. 8-3 and 8-4. Some plants might use a simpler, more conservative approach. Since $R_{TB} >> R_e$, R_e may be neglected; similarly, $R_e I_T$ in Eq. 8-4 may be neglected. Both of these result in more conservative (larger) errors. Using equation 8-4 modified only to give error as a percent of full scale and using a supply voltage of 50 Vdc, an equivalent external resistance of 1 kΩ, and a transmitter current of 4 mA (worst case) gives an error of 15.3% of full scale. (If the more conservative simplifications were used, the error would be 17.9%). The only remaining problem is that of calculating the total loop accuracy, which may be accomplished by several different methods. The most obvious and most conservative approach would be to simply add the errors giving ±(10+2+15.3)= ±27.3% total error. A second method would be to use the square root of the sum of the squares of the individual errors giving $\pm(100+4+234)^{0.5}$ = ±18.4% total error. The disadvantage of this latter method is that it assumes that each error is normally distributed about the 0% error point; in actuality, the leakage current contribution to the error can only be in the positive direction. This example is not based on any specific plant or any particular qualification test results--it serves merely as a demonstration of how the error calculations might be done. A 4-20 mA pressure transmitter circuit was chosen for this example since it is often a limiting circuit in actual plants if coaxial and triaxial cable is treated separately.

Every equipment qualification circuit in the plant should be evaluated as indicated above or in some alternative fashion. From a practical standpoint, a somewhat generic approach is desirable. One such approach used by a utility was to establish generic acceptance criteria for each individual interconnecting device. The approach might choose a value of 0.1 megohm per device (after insulation resistance has been scaled for differences between tested length and installed length), coupled with a generic reference showing that the resulting error is acceptable in plant circuits with the maximum expected number of interconnecting devices. If any device exhibits an insulation resistance less than the analyzed value, a circuit specific analysis would be performed to determine acceptability of the device.

Sandia has performed testing of Barton transmitters as reported in NUREG/CR-3863. The salient points of the research may be summarized as follows:

--The Barton transmitter electronics are extremely radiation hard, surviving a 400 Mrad total dose exposure with maximum errors around 5%.

--The major stress affecting transmitter operation is that of thermally induced errors resulting from potentiometer degradation. Barton has recommended installation of electrical isolation washers between the potentiometer and housing, which appears to reduce thermal effects by treating the symptoms of the problem.

--A potentiometer failure (open circuit) was also observed during testing. Analysis of the potentiometer indicated that corrosion was apparently responsible for the failure with the potentiometer lubricant a primary contributor to the corrosive environment.

--Time at temperature behavior indicated that thermal aging exposure may actually improve the transmitter's performance when subjected to an accident environment.

An additional concern has been identified with the gland seals used in the Barton transmitters, with several failures noted during testing by Westinghouse. The failures are manifested as moisture and corrosion products getting into the gland seal and causing corrosion and eventual opening of the lead wires. Barton has performed additional testing and analysis to justify that the anomalies were test artifacts, but some doubt still remains that the testing is conclusive for lengths of cable typically installed in plants. The analysis has been considered accepted unless additional adverse information is obtained.

One problem found for Rosemount transmitters is the failure of utilities to install plugs in the alternate cable entrance. Two cables entrances may be provided at opposite ends of the transmitter and only one is used. The other one usually has a plastic cap installed from the factory. This plastic cap must be removed and replaced with an appropriate plug.

IN 83-72
Barton xmtrs

Limit Switches

The only vendor currently known to produce qualified limit switches for inside containment, harsh environment usage is Namco. The problems with limit switches have been primarily the lack of qualified conduit seals installed on the devices. Some older models of limit switches no longer produced have had isolated instances of other problems and different models of limit switches have had some operational problems not related to qualification.

The need for qualified conduit seals arises from the method of testing the limit switches: the conduit entrance to the limit switch had sealed conduit attached and the conduit penetrated the test chamber such that the cable and switch interior were not exposed to the steam environment.

The primary effect of potential leakage currants on the operation of a limit switch would be related to false indications. The following is an analysis of the potential effects of leakage currents on a solenoid valve circuit using ... itches.

...al blocks are commonly installed in 120 Vac and 125 Vdc ...cuits for solenoid valves. Figure 8-12 is a simplified ...howing one possible solenoid valve circuit. Before addressing ... of terminal blocks, it is important to understand the normal

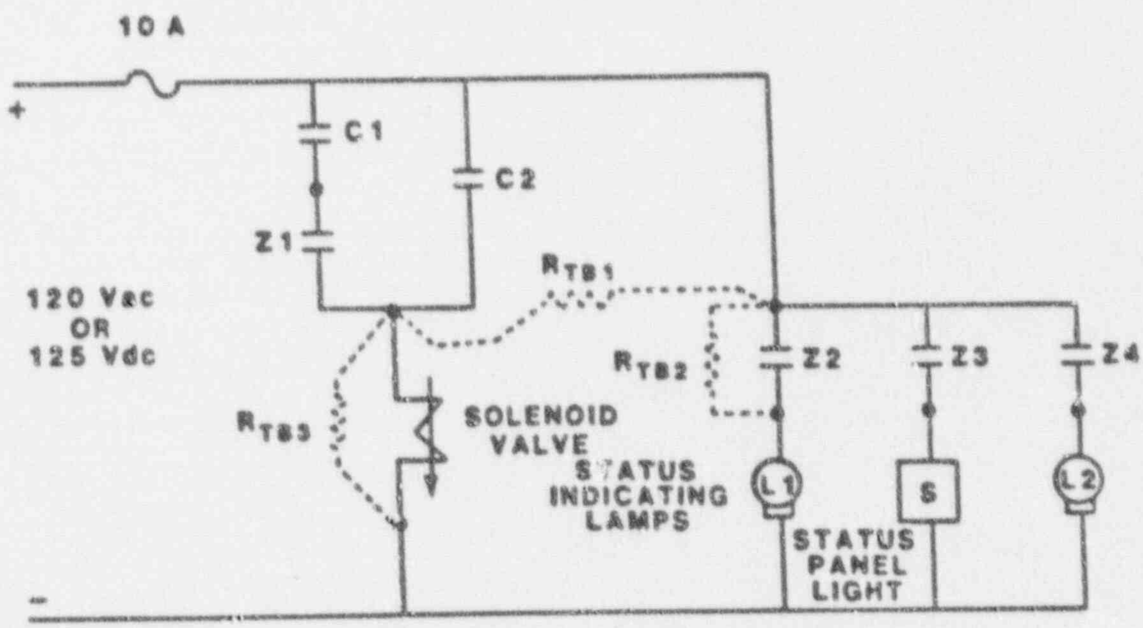


Figure 8-12: Simplified Circuit Schematic for One Possible Solenoid Valve Circuit

operation of this circuit. To begin, assume that the valve is normally open and that when energized, it closes. The desired position for operation is open.

The contacts C1 and C2 are control switches in the control room. These switches can be any one of a number of types, but a common type might be three position momentary contact switches. That is, there is a neutral position which is the rest position for the switch, and there are open and close positions which must be held by an operator in order for the switch to make contact in that position. Thus, when an operator moves the lever to open and releases it, the switches return to the neutral position. Assume that both C1 and C2 are operated by the same lever. Z1, Z2, Z3 and Z4 are two position limit switches located on the valve itself. L1 and L2 are indicator lamps in the control room and indicate that the valve is not closed and not open, respectively.* S is a status panel light which lights when the valve is in the normally desired position. Tables 8-2 and 8-3 are the contact development tables for this circuit. An "x" means that contact is made in that switch position.

Table 8-2

Contact Development Table For Control Switches C1 and C2

	---Switch and Valve Position---		
	Open	Neutral	Close
C1	-	x	x
C2	-	-	x

x = contact made
- = contact not made

* The terms "not open" and "not closed" are used rather than "closed" and "open" because that is the true meaning of the lamp. The "not open" lamp lights when the valve leaves the open position and is thus lit both while the valve is closing and when it is closed. Similarly the "not closed" lamp lights when the valve leaves the closed position and is thus lit both while the valve is opening and when it is open. If both lamps are lit simultaneously, then "not open" and "not closed" are both true which means that the valve is changing state. If only one lamp is lit, then it means that the valve is either open ("not closed") or closed ("not open").

Table 8-3

Contact Development Table for Limit Switches Z1, Z2, Z3, and Z4

	---------Valve Position---------		
	Open	Intermediate	Close
Z1	-	-	x
Z2	x	x	-
Z3	x	-	-
Z4	-	x	x

x = contact made
– = contact not made

If the valve is open, we see from Tables 8-2 and 8-3 that C1, C2, Z1, and Z4 are open. Only Z2 and Z3 are closed which means L1 and S are lit and the indication is that the valve is open (see footnote on "not open" and "not closed"). If the operator now wants to close the valve, he moves the lever for C1 and C2 to the "close" position. Both C1 and C2 make contact and, because Z1 is still open, power is applied to the valve via C2. The valve begins to close; Z3 trips open extinguishing S and Z4 trips closed lighting L2. Both L1 and L2 are now lit, and hence we know the valve is changing position. If the operator releases the lever before the valve is fully closed it will return to the full open (nonenergized) position since Z1 is not yet closed and C2 is open when in the neutral position. When the valve reaches the fully closed position, Z1 and Z2 change state. Z1 closes so that when the operator releases the switch lever, power to the valve will be applied through C1 and Z1; Z2 opens turning L1 off. The sequence happens in reverse when opening a closed valve. The operator moves the switch lever to open, thus opening C1; C2 was already open. Power to the valve is lost and it begins to open. As it does, Z1 and Z2 change state. Z1 opens to ensure that power will not be reapplied when C1 is released to the neutral position. Z2 closes, lighting L1. When the valve reaches fully open, Z3 and Z4 change state. Z3 closes, lighting S, and Z4 opens turning L2 off.

The dots in Figure 8-12 indicate circuit nodes which are physical junctions to field wiring near the valve. These may very likely be adjacent terminals on a terminal block. Three possible terminal block leakage paths have been indicated on Figure 8-12 by dotted resistors. Each may have a detrimental effect on the operation of the solenoid circuit. First, consider R_{TB1}, a leakage path between the always powered node of Z2, Z3, and Z4, and the solenoid valve. This leakage path bypasses the valve control switches C1, C2, and Z1. The effect of this leakage current could be the inadvertent energizing of the valve when a steam environment quickly envelopes the terminal block. If R_{TB1} is small enough, a leakage current sufficient to power the valve may occur. If the valve in question is a 17.4 watt, dc service valve, then the steady state resistance of the valve is:

$$R_V = \frac{(125\ V)^2}{17.4\ W} = 900\ \Omega$$

In actuality, because of the finite value of R_{TB1}, the entire power supply potential will not be dropped across the solenoid valve. The minimum voltage to actuate the valve is approximately 90 Vdc [49] and hence the current necessary for this condition is:

$$I_V = \frac{90\ V}{900\ \Omega} = 0.1\ A$$

If at least 90 volts must drop across the solenoid valve, then a maximum of 35 volts can drop across R_{TB1}. Using the 0.1 A current requirement to operate the valve, we see that:

$$R_{TB1} = \frac{35\ V}{0.1\ A} = 350\ \Omega$$

Thus, a transient terminal block insulation resistance of 350 ohms would cause the valve to close when it was intended to be open. Industry qualification tests experience leakage currents sufficiently large to indicate that such low IR values are possible. Further, low values of IR would be most likely to occur under transient conditions (see Figures 4-6 and 8-3). The question here is whether or not such low values of IR would prevail for a period sufficiently long to complete the closing of the valve. Sandia test results indicate that the answer is probably yes, because solenoid actuation is fairly rapid and the low values of terminal block IR prevailed for seconds to minutes after their onset.

Next consider the leakage path designated by R_{TB2}. This path is a leakage path by limit switch Z2 and the net result could be a false lighting of indicating lamp L1. Analogous paths, not shown in Figure 8-12, would erroneously light lamps L2 or S. The current and voltage required to light L1 will undoubtedly vary from design to design, but two cases might be considered as examples. In the first case, the lamp is in a series connection as shown in Figure 8-12. A typical 125 Vdc lamp for such an application might require a minimum of 110 Vdc to operate.[50] The lamp itself might typically have a resistance of 2000 ohms and hence the current necessary would be:

$$I_{Lamp} = \frac{110\ V}{2000\ \Omega} = 0.055\ A$$

Thus, the terminal block insulation resistance would have to be:

$$R_{TB2} = \frac{15\ V}{0.055\ A} = 273\ \Omega$$

Again, this value of IR is not unreasonable for transient conditions though sustained values at this low level are unlikely.

The second lamp configuration would replace the actual lamps with a relay which would turn separately powered lamps on or off. Thus L1, L2, and S would be the pick-up coils for these relays. Such relays might typically have a pick-up voltage of 75 percent of the rated voltage and a coil resistance of 13000 ohms. The required current therefore would be:

$$I_{relay} = \frac{(0.75)(125\ V)}{13000\ \Omega} = 0.0072\ A$$

The voltage drop across the terminal block could be at most 25% of 125 Vdc or 31 Vdc and hence:

$$R_{TB2} = \frac{31\ V}{0.0072\ A} = 4300\ \Omega$$

Thus, a much larger terminal block IR would permit false operation of the indicating or status lamps if they were switched on and off by a relay. Any value of R_{TB2} less than 4300 ohms would cause the lamps to falsely illuminate for the assumed type of relay.

The final fault shown in Figure 8-12 is R_{TB3}. This path leaks by the valve itself and would cause a problem only if the leakage current became large enough to make the circuit fuse fail. For the worst case with a 17.4 watt dc valve energized and all three lamps illuminated, the current in the circuit would be:

$$I_{max} = \frac{17.4\ W}{125\ V} + 3 \cdot \frac{125\ V}{2000\ \Omega} = 0.327\ A$$

If the circuit were fused at 10 A, then 9.673 A would have to leak around the valve to cause the fuse to fail. With the valve remaining energized at 125 V, fuse failure would occur at a terminal block IR of:

$$R_{TB3} = \frac{125\ V}{9.673\ A} = 13\ \Omega$$

This value is essentially a dead short; however, if the circuit were fused at 1 A, fuse failure would occur at a terminal block IR of 186 ohms. These low IR values are not impossible to achieve, but for any sustained period seem improbable. Momentary high leakage currents may cause the fuse to open. At these high leakage current levels, one must also be concerned with the power being dissipated by the terminal block and the effect such power dissipation may have on permanently degrading the block's surface.

In summary, the above discussion indicates that terminal blocks may interfere with the proper operation of a solenoid valve circuit when the terminal block's insulation resistance decreases to about the 4 kohm level. At this value of terminal block IR, indicating lamps may falsely light depending on how they are wired into the circuit. At a few hundred ohms of insulation resistance, the valve may falsely energize and at a few ohms of insulation resistance the leakage current may be large enough to fail circuit fuses. Being slightly conservative, we may conclude that at IR values above 5 kohms, terminal blocks probably do not affect the operation of solenoid valve circuits.

High Range Radiation Monitors (HRRM)

The primary deficiency noted with radiation monitors has been the failure to meet performance requirements set forth by RG 1.97. The General Atomics (GA) HRRM has been tested and analyzed at Sandia and the report (NUREG/CR-4728) will be issued shortly. The major conclusions of the report are as follows:

--The HRRM accurately monitors high dose rates during accident conditions.

--The HRRM does not always accurately monitor low dose rates in accident environments.

--One failure mechanism for the above is due to insulation resistances of interconnecting devices failing to meet the GA specifications of $10^9 \Omega$ each for the electrical penetration and the other interconnections considered together (for a net parallel IR of $5 \times 10^8 \Omega$ minimum). The industry had not previously recognized this problem.

--A second failure mode at low dose rates involves an unknown mechanism, postulated to possibly be galvanic action.

--The operate light on the GA monitor will likely go out early during accident conditions, indicating a fault with the monitor; resetting the monitor will allow it to operate properly if the dose rate has increased sufficiently. However, without knowing the details of the detector operation, operators could potentially be misled by the failure indication.

--The effects of interconnection IR can be modelled by a fairly simple technique, but the other effect is still somewhat unknown. The following gives an analysis of IR effects on the GA HRRM:

We believe that knowledge of the offset voltage characteristics of the readout module's input operational amplifier is critical to assessing the loss of accuracy of the readout module due to insulation resistance effects. To illustrate the point, an operational amplifier circuit is shown in Figure 13. In this circuit, under ideal conditions, all of the input current is diverted around the input amplifier and through select feedback elements. Under these conditions, the negative terminal of the input amplifier acts as a "virtual" ground, i.e. the voltage across the amplifier inputs, V_1, is very nearly at ground potential. The output voltage of the amplifier must be $V_{out} = -A*V_1$, where A is the open loop amplifier gain. (The amplifier gain could vary over a wide range, but a typical value might be around 2×10^5.) The actual voltage V_1 is "adjusted" by the feedback elements such that the desired closed loop properties of the output voltage are achieved. As an example of the voltage at V_1, consider the above open loop amplifier gain and an output voltage of 5.0 V. The resulting voltage V_1 is easily calculated as 0.025 mV (indeed a "virtual" ground). Any input offset voltage is automatically compensated for by the feedback elements since

With $I_{in} = (V_1 + V_{os}) / R_{in}$, where V_{os} is the amplifier input offset voltage, (2) becomes:

$$\frac{-V_1}{R_{ins}} + I_{det} = \frac{V_1 + V_{os}}{R_{in}} \qquad (3)$$

Solving (3) for V_1 gives:

$$V_1 = \left[\frac{R_{in} R_{ins}}{R_{in} + R_{ins}} \right] \left[I_{det} - \frac{V_{os}}{R_{in}} \right] \qquad (4)$$

Finally, using (4) in (2) and rearranging gives:

$$I_{det} = I_{in} \left[\frac{R_{ins}}{R_{in} + R_{ins}} \right] - \frac{V_{os}}{R_{in} + R_{ins}} \qquad (5)$$

Equation (5) gives an expression for the current actually measured by the readout module for a given offset voltage and a given insulation resistance between the center conductor and shield of the coaxial cable.

Equation (5) works quite well for IR effects as has been verified over a range of values based on experimental Sandia data. It should be emphasized that this assessment required the knowledge of the input offset voltage of the readout module input operational amplifier. The offset voltage is a random parameter and might typically be within the range of -3.0 mV to +3.0 mV. Consequently, without knowing the input offset voltage for a given device, neither the magnitude nor even the direction of the error is predictable. However, given the manufacturer's specifications for the input amplifier, bounds can be put on the IR-induced error as a function of the detector current and the interconnection insulation resistance by using equation (5).

Equation (5) can also be used to give a qualitative assessment of the readout module's behavior by considering the two terms of the equation separately. The first term represents the loss of signal generated by leakage of detector current to ground; the factor in parenthesis is always a positive quantity less than 1.0. The second term represents the contribution of the amplifier input offset voltage to the input current and may be either positive or negative. If the input offset voltage is positive (as in our case), it causes additional current to flow into the readout input because V_1 is approximately the negative of the offset voltage and is thus below ground potential, causing current to be drawn from ground. A reverse argument holds for a negative offset voltage, but the result is current drawn from the readout module. In this second case, at low detector currents, the readout module will tend toward going off-scale on the low end (due to both terms). At low detector currents, the second term of equation (5) tends to control readout behavior, while at high detector currents, the first term tends to control the behavior. For any given interconnection insulation resistance, the undesirable effects modelled by equation (5) are much more pronounced for the low detector currents (mainly the second term of equation (5)).

It should be emphasized that the effects modelled by equation (5) are only IR induced. Another effect, which was not even positively identified, tended to dominate detector behavior at low detector currents. Consequently, analysis using calculations such as equation (5) may be of somewhat limited value.

The other major detector used by the industry (Victoreen) has not been tested or evaluated as the GA has. Some of the above concerns may also apply to the Victoreen. The Victoreen HRRM includes installation requirements that the cable used be installed in sealed conduit. This requirement came about from the numerous difficulties and anomalies that were encountered in testing of the detector. One piece of information in the Victoreen qualification indicates that a loop IR of 10^6 Ω is sufficient for detector operation, but no basis is given for this value. (The GA requirement also gives no basis, but the equation developed above can be used to show that the GA criteria is adequate if a reasonable worst-case amplifier offset voltage is assumed.)

Appendix B
Activation Energies

B.1 TABULATION

Activation energies for a number of materials and components are tabulated in this appendix. As in Appendix D, no effort was made to produce an exhaustive tabulation; rather, it is a convenient recording of activation energy data obtained incidentally to preparation of this report. It is essential that the cited data sources be consulted to verify the relevance to the user's application.

B.2 HISTOGRAM

A graphical representation of the distribution of activation energies, for the materials and components included in the tabulation, is given by the histogram in Figure B-1.

The values of activation energy range from 0.09 eV for titanium-titanium dioxide, thin-film capacitors to 3.29 eV for Kraft paper. This range was divided into 0.2-eV increments, and the number of materials and components that have an activation energy within a given increment was counted (from the tabulation). These numbers were then used to plot the histogram. The large number of entries for magnet wire contributes substantially to the histogram over a broad range from 0.2 to 1.8 eV, except in the interval between 1.2 and 1.4 eV. Polymers and transistors make a major contribution to the peak between 1.0 and 1.2 eV.

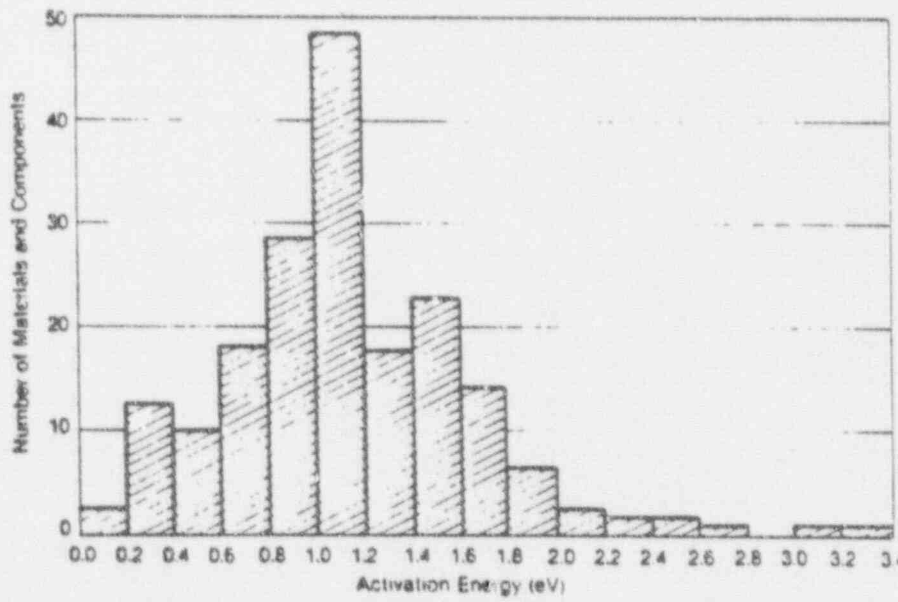


Figure B-1.
Histogram of Activation Energies

NOTES FOR TABULATED ACTIVATION ENERGIES

Notes:

1. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). No impregnate.
2. Encapsulated with aliphatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy cast). Impregnated.
3. Encapsulated with B staged aromatic amine cured bisphenol A-epichlorhydrin epoxide (epoxy transfer molded). No impregnate.
4. Encapsulated with B staged aromatic amine cured bisphenol A epichlorhydrin epoxide (epoxy transfer molded). Impregnated.
5. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot melt). No impregnate.
6. Encapsulated with phthalic anhydride cured bisphenol A-epichlorhydrin epoxide (epoxy hot melt cast). Impregnated.
7. Encapsulated with modified anhydride cured bisphenol A-epichlorhydrin epoxide. No impregnate.
8. Encapsulated with mixed anhydride cured epoxy novolac. No impregnate.
9. Failure criteria: cracking of insulation to expose conductor, dielectric breakdown leakage current > 300 μA at 3000 V. All specimens tested to failure.
10. Failure criterion: voltage stress of 3000 volts held for 15 seconds at 100% R.H. All specimens tested to failure.
11. Based on graph of log (mean time to failure) vs. 1/T.
12. Failure criterion: 3 A drawn at rated voltage. All samples tested to failure.
13. Burned in @ 125°C, then powered during life testing @ 250°C. Main failure mode was high leakage currents.
14. Calculated from Arrhenius-type plots.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Alkyd, Grade 1500	1.71	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Alkyd, Grade 1500	1.14	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Alken-imide, irradiated, insulation, 20 gauge wire	0.88	461	MIL-W-81044/17A. Mean time to failure. Notes 9 and 14.
Aromatic polyimide, insulation, 20 gauge wire	1.29	461	MIL-W-81381/12. Mean time to failure. Notes 9 and 14.
Butyl	1.08	603	40% loss of elongation. See Note 14.
Capacitors, chlorinated diphenyl. No stabilizers.	1.17	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl. 0.5% anthraquinone	1.53	566	DC life. Stressed at 1000 volts per mil. See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Capacitors, chlorinated diphenyl. 0.5% azobenzene	2.00	566	DC life. Stressed at 1000 volts per mil. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper	0.86	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 0.5% azobenzene	1.50	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14.
Capacitors, chlorinated diphenyl Kraft paper with 5.0% azobenzene	1.93	180	Dielectric stressed with dc potential, 10^6 V/in. See Note 14
Capacitor, dielectric, tubular paper	2.42	717	10% capacitance increase. See Note 14.
Capacitors, metalized paper	1.32	180	Life defined as time required to regain original value of capacitance after initial increase. See Note 14.
Capacitors, titanium-titanium dioxide, thin-film. @ 25°C-100°C	0.09	466	Formed by anodization. Tests with rate of temperature rise approximately 2½°C/min.
Choseal (Chomeric Inc.) (Silver filled conductive silicone)	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Connectors: Thin gold (25-100μ) electroplated over copper base material			$D = D_o \exp(\varphi/kT)$, where D = chemical interdiffusion coefficient and $D_o \cong 1.5 \times 10^{-5}$ cm²/s.
(250°C - 750°C)	1.02	433	Predominant degradation mechanism is defect diffusion along grain boundaries and dislocation pipes—dependent upon defect density.
(50°C - 250°C)	0.50	433	
Dacron, Parachute material (polyethylene glycol terephthalate, see see Ref. 124)	1.15	765	Determined by thermogravimetric analysis. Heating rate of 2°C per minute
Diallyphthalate, glass filled	1.04	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Diodes, Si —general	1.13-2.77	340	
Diodes, Si (—1960)	1.14	340	

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Diode, silicon, 1N673 and 1N696	1.80	339	50% failure. See Note 14.
Diodes, silicon, p-n-p-*n*	1.41	340	
Diodes, silicon, varactors	2.31-2.38	340	
Diodes, others	1.13-2.77	340	
Diodes, varactors	2.31-2.38	340	
Ethylene propylene, No. 8 lead wire with paper separator	0.71	374	See Note 14.
Ethylene propylene	1.28	51	20% loss in elongation. See Note 14.
Ethylene propylene base insulation	1.05	603	40% loss of elongation. See Note 14.
Ethylene propylene, No. 18 lead wire	0.90	374	Estimated average life. See Note 14.
Ethylene propylene, solid—with paper separator	0.70	374	10,000 h life @112°C
Ethylene propylene, solid	0.95	374	10,000 h life @132°C
Enamel, plain, insulation on magnet wire	0.35	610	See Notes 3, 11 and 14.
Enamel, plain, insulation on magnet wire	0.64	610	See Notes 2, 11 and 14.
Enamel, plain, insulation on magnet wire	1.61	610	See Notes 1, 11 and 14.
Enamel, plain, insulation on magnet wire	0.38	610	See Notes 4, 11 and 14.
Enamel, plain, insulation on magnet wire	0.45	610	See Notes 5, 11 and 14.
Enamel, plain, insulation on magnet wire	0.28	610	See Notes 6, 11 and 14.
Epon 828 (Shell Chemical)	1.34	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Epoxy (epoxide film), insulation, magnet wire	0.71	368	See Note 14.
Epoxy, Grade 2000	0.98	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Epoxy, Grade 2000	1.24	1026	50% retention of dielectric strength (Hooker Corp.). See Note 14.
Epoxy insulation on magnet wire	0.99	610	See Notes 1 and 11.
Epoxy insulation on magnet wire	0.94	610	See Notes 2 and 11.
Epoxy insulation on magnet wire	0.87	610	See Notes 3 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 4 and 11.
Epoxy insulation on magnet wire	0.73	610	See Notes 5 and 11.
Epoxy insulation on magnet wire	0.93	610	See Notes 6 and 11.
Epoxy, unvarnished, magnet wire	0.67	832	See Note 14.
Epoxy, phenolic varnished, magnet wire	0.66	832	See Note 14.
Formvar (Bondege), cementable insulation and Andover Corp. epoxy encapsulant	1.09	320	See Note 14.
Formvar, cementable insulation and epoxy encapsulant – solenoid coil	0.70	320	See Note 14.
Formvar insulation on magnet wire	1.61	610	See Notes 1 and 11.
Formvar insulation on magnet wire	0.23	610	See Notes 3 and 11.
Glass, high lead	0.37	97	
Isonel – 175 insulation and Acme 2008 epoxy encapsulant on solenoid coil.	0.68	320	Average coil life. See Notes 12 and 14.
Kraft paper in mineral oil.	1.39	838	50% of tensile strength. See Note 14.
Kynar. MIL-specification wires	1.95	374	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Microcircuits, CMOS type CD 4024A	1.0	795	25h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS type CD 4013A	1.1	795	42h @ 250°C = 50% failure. See Note 13.
Microcircuits, CMOS, type CD 4011A	1.4	795	90h @ 250°C = 50% failure. See Note 13.
Microcircuit, CMOS			
4007 freak pop.	0.9	517	
main pop.	1.3	517	
ML #18 twist pairs	1.43	610	See Notes 7 and 11.
ML #33 coils	1.15	610	See Note 8. Failure criteria was shorted turn, open circuit and/or 2500 volt hipot failure of coil.
ML #18 twist pairs	-2.44	610	See Note 8.
Mylar film	1.18	589	Data based on 50% electric strength failure. See Note 14.
Neoprene	0.87	401	70°C - 130°C.
Nitrile	0.86	401	70°C – 100°C.
Nyleze insulation on magnet wire	0.57	610	See Notes 6 and 11.
Nyleze insulation on magnet wire	0.99	610	See Notes 1, 11 and 14.
Nyleze insulation on magnet wire	0.75	610	See Notes 2, 11 and 14.
Nyleze insulation on magnet wire	0.68	610	See Notes 3, 11 and 14.
Nyleze insulation on magnet wire	0.59	610	See Notes 4, 11 and 14.
Nyleze insulation on magnet wire	1.04	610	See Notes 5, 11 and 14.
Nylon 6/6, glass-reinforced	1.14	530	Tested at 205 and 255°C. 50% reduction in tensile strength. See Note 14.
Nylon 6/6, glass-reinforced	1.29	530	Tested at 140 and 150°C. 50% reduction in tensile strength. See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Operational Amplifier 741			
– freak pop.	0.7	517	
– main pop.	1.6	517	
– mixed pop.	0.8	517	
– freak pop.	0.8	517	
– main pop. (1/2 voltage)	0.9	517	
Paper, manila, under oil	1.66	566	Reduction of tensile strength to 20% of original strength. See Note 14.
Paper, manila, under oil	1.56	566	Reduction of tensile strength to 70% original strength. See Note 14.
Penolic, general purpose, Durez 791	1.36	1026	50% retention of impact strength (Hooker Corp.). See Note 14.
Phenolic, general purpose, Durez 791	1.05	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	0.96	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 666	1.11	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.16	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 649	1.43	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic, Grade 685	1.27	1026	50% retention of flexural strength (Hooker Corp.). See Note 14.
Phenolic-Kraft laminate	1.47	573	75% retention of flexural strength. See Note 14.
Phenolic-Kraft laminate	1.50	573	50% retention of flexural strength. See Note 14.
Polyester, amide-imide overcoated, helical coil	1.54	943	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyester, amide-imide overcoated, wire, twisted pairs	1.25	943	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating varnish	1.26	832	See Note 14.
Polyester-overcoated, magnet wire and class 155 impregnating var- nish, in motorette systems	1.66	832	See Note 14.
Polyester-overcoated, unvarnished twists of magnet wire.	1.44	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.67	832	See Note 14.
Polyester-overcoated, magnet wire twists with modified silicone varnish.	1.86	832	See Note 14.
Polyester, phenolic varnished, magnet wire.	1.04	832	See Note 14.
Polyester resins (unjelled) Hetron 24505, 853, 354 and Maro 670.	0.87	358	
Polyester, unvarnished, magnet wire.	1.00	832	See Note 14.
Polyethylene, cross-linked	1.13	603	40% loss of elongation. See Note 14.
Polyethelene, cross-linked	1.23	51	20% loss in elongation. See Note 14.
Polyethylene, 0.92 density	1.15	973	t_{10} induction periods. See Note 14.
Polyethylene, low density (below 97°C)	1.51	973	Extrapolated induction periods. See Note 14.
Polyethylene, 0.96 density	1.14	973	t_{10} induction periods. See Note 14.
Polyethylene, low density	1.35	973	(Above 110°C) extrapolated induction periods. See Note 14.
Polyethylene, linear	3.10	537	10% weight loss in vacuum. See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polypropylene, isotactic	1.13	973	t_{10} induction periods. See Note 14.
Polyalkene – polyvinylidene fluoride, irradiated, insulation, 20 gauge wire.	1.10	461	MIL-W-81044/9. Mean time to failure. See Notes 9 and 14.
Printed circuit board material (1/32 in.), NEMA G-10 and FR-4	1.05	717	50% retention of electrical strength. See Note 14.
Printed circuit board material (1/32 in.) NEMA G-10 and FR-4	1.49	717	50% retention of flexural strength. See Note 14.
Polyimide, aromatic, TFE-banded and coated insulation, 20 gauge wire.	1.57	461	Meantime to failure. See Notes 9 and 14.
Polymethylmethacrylate	0.34	890	
Polytetrafluoroethelene	0.43	890	
Polytetrafluoroethylene	3.29	537	10% weight loss in vacuum. See Note 14.
Polythermaleze, heavy, insulation and 3M 241 epoxy encapsulant on solenoid coil.	0.95	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation and Acme 4027-A epoxy encapsulant on solenoid coil.	0.92	320	Average coil life. See Notes 12 and 14.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 1 and 11.
Polythermaleze insulation on magnet wire.	0.96	610	See Notes 2 and 11.
Polythermaleze insulation on magnet wire.	1.56	610	See Notes 3 and 11.
Polythermaleze insulation on magnet wire.	1.00	610	See Notes 4 and 11.
Polythermaleze insulation on magnet wire.	0.98	610	See Notes 5 and 11.
Polythermaleze insulation on magnet wire.	0.75	610	See Notes 6 and 11.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polythermaleze #33 on coils.	0.87	610	See Note 7. Failure criteria was shorted turn, open circuit and/ or 2500 volt hipot failure of coil.
Polystyrene	0.26	890	
Polyurethane insulation on magnet wire.	0.49	610	See Notes 6 and 11.
Polyurethane insulation on magnet wire.	0.29	610	See Notes 4 and 11.
Polyurethane insulation on magnet w	0.32	610	See Notes 5 and 11.
Polyurethane insulation on magnet wire.	0.38	610	See Notes 2 and 11.
Polyurethane insulation on magnet wire.	0.28	610	See Notes 3 and 11.
Polyurethane insulation on magnet wire.	0.46	610	See Notes 1 and 11.
Polyvinylacetate	0.16	890	
Polyvinylchloride	0.26	890	
Polyvinyl formal, magnet wire twists, with phenolic alkyd varnish.	0.80	832	See Note 14.
Polyvinyl formal, magnet wire, with phenolic type varnish.	0.82	832	See Note 14.
Polyvinyl formal, with phenolic type varnish, magnet wire.	0.93	832	See Note 14.
Polyvinyl formal, with phenolic type impregnating varnish, magnet wire.	1.04	832	See Note 14.
Polyvinyl formal, unvarnished, magnet wire.	1.01	832	See Note 14.
Polyvinyl formal enamel and oil modified phenolic varnish, magnet wire.	0.98	368	See Note 14.
Polyvinyl formal, un-phenolic type varnish, magnet wire.	0.84	832	See Note 14.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Polyvinyl formal, impregnated with phenolic type varnish, magnet wire.	1.03	832	See Note 14.
PVC-nylon insulation, 20 gauge wire	1.40	461	MIL-W-5086/2. See Notes 9 and 14.
PVC, irradiated, insulation, 20 gauge wire.	0.99	461	See Notes 9 and 14.
Resin-mica insulation, solventless	0.70	179	Loss factor in stator coils during 10-year field service increased in accordance with Arrhenius model to a peak.
Semiconductor devices, silicon.	0.9-1.4	86	Predominant value – 1.1 eV.
Silicon 6-110-6 (Dow Corning)	1.14	755	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Silicone, modified, wire enamel on copper without varnish.	1.56	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on copper with silicone varnish.	1.61	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicone, modified, wire enamel on aluminum without varnish.	1.46	566	1000 volt failure between twisted pairs. Average life. See Note 14.
Silicon transistors and integrated circuits	1.1	184	Testing of transistors and integrated circuits based on Arrhenius model.
SML insulation and Jones-Dabney epoxy encapsulant.	0.72	320	See Note 14.
Termination, tinned round wire (Sn, Sn + SnPb, Au, Ag)	0.77	69	Present aging relation: 16 h @ 155°C = 5 yr @ room temp. Recommended relation: 4 h @ 155°C = 5 yr @ room temp. Failure caused by: high temperature, high humidity, sulfur-dioxide.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Thermaleze "B" (epoxy polyester film), insulation magnet wire.	1.0	368	See Note 14.
Thermaleze-F insulation and Jones-Dabney epoxy encapsulant.	1.10	320	See Note 14.
Thermalon insulation and 3M 241 epoxy encapsulate on solenoid coil.	0.42	320	Average coil life. See Notes 12 and 14.
Transistors	0.66	123	
Transistor, Ge alloyed, OC 1972 (1964)	1.26	235	
(1966)	1.08	235	
Transistor, Ge alloy LT123 (1958).	1.25	670	
Transistor, bipolar, p-n-p-n	1.65	340	
Transistors, CMOS	1.18	334	Eyring model.
Transistor, diffused-geronium	0.87	340	Step-stress tests without moisture getter. Median life. See Note 14.
Transistor, diffused-germanium	1.24	340	Constant stress tests with moisture getter. Median life. See Note 14.
Transistor, Ge gettered	1.24	340	
Transistor, Ge mesa, AF106 (1969)	1.00	235	
Transistor, Ge mesa, 2N559 (1958)	1.17	671	
(1959)	0.95	671	
(1960)	1.14	671	
Transistor, Ge MADT, 2N501 (1958)	1.07	673	MADT = Micro alloy diffused transistor
Ge MADT, 2N501 (1959)	1.07	674	
Transistor, Ge MAT, 2N393 (1960)	1.0	673	MAT = Micro alloy transistor
Transistor, Ge MAT, 2N393 (1959)	1.00	673	MAT = Micro alloy transistor
Transistor, Ge ungettered	0.88	340	

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Transistors, germanium @ 60°C.	0.99-1.26	136 (Appendix)	
Transistors, germanium	0.17	236	Near and below room temperature
Transistor, germanium, ungettered	0.88	340	
Transistors, germanium, gettered with vycor or molecular sieve	1.24	340	
Transistor, Si mesa, 2N269 (1961)	0.38	677	Conditions not specified.
	0.58	677	Constant stress.
Transistor, Si mesa, 2N560 (1959)	1.12	672	
(1960)	1.50	672	
Transistor, Si mesa, 2N1051 (1960)	-1.12	671	
Transistor, modern submarine cable	1.4	129	
Transistors, MOS	1.2	129	
Transistors, MOS	1.10	157	Median life for failure criterion of 1.0-V shift. See Note 14.
Transistors, MOS	1.10	157	Median life for failure criterion of 0.5-V shift. See Note 14.
Transistor, power, MSC 1330	0.81	125	Median time to failure. See Note 14.
Transistors, Si main pop. (1960)	1.02	340	
Transistor, Si planar, BFY 33 (1969)	1.12	235	
Transistor, Si planar, 4A-2(1967)	1.18	675	Step stress.
(1967)	1.50	675	Constant stress.
(1963)	1.29	676	Constant stress.
Transistor, Si, p-n-p-n	1.65	340	
Transistors, silicon, (All) —before wearout	1.12	235	
—at wearout	1.46	235	
Transistor, silicon, bipolar	1.02	340	With surface inversion failures.
Transistor, silicon, bipolar	1.02-1.04	340	With Au-Al bond failures.

Material/ Component/Device	Activation Energy (eV)	Citation	Remarks
Transistor, silicon, bipolar	1.77	340	With metal penetration into Si.
Transistor, silicone mesa, 2N560	2.16	339	50% failure. See Note 14.
Transistors, silicon, typical	0.96	340	t_{10} lifeline. See Note 14.
Transistors, silicon, typical	1.11	340	t_{50} lifeline. See Note 14.
Transistors, submarine-cable	1.30	157	0.025% failure. See Note 14.
Transistors, submarine-cable	1.24	129	50% failure. See Note 14.
Transistors, 2N559, vacuum baked.	0.89	750	Median life based on failure criteria of collector breakdown voltage and reverse current, and emitter breakdown voltage. See Note 14.
Transistor, Vycor gettered germanium, 2N559.	1.02	339	50% failure. See Note 14.
Viton A (DuPont)	1.11	765	Determined by thermogravimetric analysis. Heating rate of 10°C per minute.
Wire, aircraft, Type I, Size 14	1.66	360	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type II, Size 8	1.77	368	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type II, Size 14.	1.56	368	MIL-W-4086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 14.	1.57	368	MIL-W-5086A. Average life. See Notes 10 and 14.
Wire, aircraft, Type III, Size 8.	1.96	368	MIL-W-5086A. Average life. See Notes 10 and 14.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

HW

JUN 0 8 1988

#139

MEMORANDUM FOR: Brian K. Grimes, Acting Director
Division of Reactor Inspection and Safeguards
Office of Nuclear Reactor Regulation

FROM: E. William Brach, Chief
Vendor Inspection Branch
Division of Reactor Inspection and Safeguards
Of..ce of Nuclear Reactor Regulation

SUBJECT: ENVIRONMENTAL QUALIFICATION MEETING WITH REGIONAL COUNTERPARTS

On the morning of June 1, 1988 a meeting was held at White Flint with EQ technical counterparts from all five regions. In the afternoon, the meeting continued at Maryland National Bank Building with participants in the monthly enforcement counterparts meeting.

Enclosed are notes and an attendance list for the morning technical session.

E. William Brach, Chief
Vendor Inspection Branch
Division of Reactor Inspection and Safeguards
Office of Nuclear Reactor Regulation

Enclosure:
As stated

cc: ~~J.~~ Lieberman
L. Shao

EQ TECHNICAL COUNTERPART MEETING

WHITE FLINT - JUNE 1, 1988, 8:00-12:00 AM

Objective: Assure uniform classification of findings resulting from first round EQ inspections based on the enforcement policy of Generic Letter 88-07.

Scope: The discussion concentrated on staff positions on specific components and deficiencies.

Commitments: Vendor Inspection Branch, SPIS agreed to continue informal review and concurrence for the following:

1. Draft enforcement classifications for first round inspections.

2. Closeout actions for first round follow-up inspections.

ATTENDANCE

Name	Region
John Burdoin	RV
Alan Herdt	RII
Dick Wilson	HQ
Steve Alexander	HQ
Al Johnson	RIV
Johns Jaudon	RIV
Leonard Cheung	RI
J. J. Harrison	RIII
Daniel Holody	RI
Howard Wong	HQ
George Hubbard	HQ
Anil S. Gautam	RIII
Uldis Potapovs	HQ
Bill Brach	HQ
Cliff Anderson	RI
Harold Walker	HQ
Jack Kudrick	HQ
Al Johnson	RV

AGENDA

EQ TECHNICAL COUNTERPART MEETING

June 1, 1988

R[illegible], White Flint North

AM Session (8:00 - 12:00)

Introduction & Discussion of Agenda

EQ - Historical Overview/Key Documents

GL 88-07 - Definition of Terms/Classification of Findings

Staff Positions on Significant Issues

- Similarity Arguments (Cable)
- Moisture Intrusion/Entrance Seals
- Instrument Accuracy
- Use of Commercial Grade Items (C of C's)

Staff Positions on Specific Items

- Valve Operators (T-drains, Wire Connectors, etc.)
- Lubricants
- Containment Penetrations
- High Range Radiation Monitors
- Terminal Blocks
- Solenoid Valves

PM Session (1:30 - 4:30) - With Enforcement Staff/Coordinators

Policy Overview

Enforcement Guidance Memo 88-XX

"Should Have Known" Arguments

Discussion of Specific Cases

Special Issues

- Enforcement of "Post-First Round" Findings/Closing Open Items
- Plants Inspected Before November 1985 Deadline
- Different Enforcement Criteria for Two Plants on Same Site

Plans for Future Meetings

AGENDA

June 1, 1988

1:30 - 4:00 (approximately)	ENVIRONMENTAL QUALIFICATION	Enforcement, OGC, and Technical Staff Discussions

June 2, 1988

7:45 - 8:00	INTRODUCTION AND DISCUSSION OF DAY'S AGENDA	James Lieberman
8:00 - 9:00	POTENTIAL REVISIONS TO NRC ENFORCEMENT POLICY	James Lieberman
9:00 - 9:30	UPDATE ON REVISED ENFORCEMENT SUPPLEMENTS	Security - D. Rosano Transportation - E. Flack Medical - J. Johansen
9:30 - 9:45	BREAK	
9:45 - 10:30	OGC ENFORCEMENT ISSUES	L. Chandler
10:30 - 11:00	ENFORCEMENT ACTIONS INVOLVING INDIVIDUALS	Licensed - J. Luehman Others (Blacklisting) J. Lieberman
11:00 - 11:30	3M UPDATE AND OTHER CURRENT ISSUES	Flack/NMSS
11:30 - 12:00	T.S. 3.0.3 AND RELATED SPECIFICATIONS	H. Wong
12:00 - 12:45	LUNCH	
12:45 - 1:15	OPERABLE/OPERABILITY AND USE OF MANUAL ACTIONS IN PLACE OF AUTOMATIC FUNCTIONS	J. Luehman/H. Wong
1:15 - 2:00	STATUTE OF LIMITATIONS - USE OF 50.59 AND 10 CFR 50 APPENDIX B	H. Wong
2:00 - 2:15	BREAK	
2:15 - 3:30	DISCUSSION - OTHER TOPICS OF CONCERN OR INTEREST	Enforcement Coordinators
3:30 - 4:30	CLOSING REMARKS	J. Lieberman

6/1/88 -

WORST CASES

RI - ([illegible])

RII - ROBINSON
FARLEY

RIII - PALISADES
BIG ROCK PT

RIV - [COOPER]

RV - WNP-2
PG&E -

DO WORST CASES FIRST

CLEARER [illegible] IN COVER LTR TO EXPLAIN EX VIOL. CATEGORY

3-6 MONTHS - PUT TO OE W/ [illegible] CASES FIRST
(1 MONTH [illegible]
CASES IN [illegible]
REPORT)

LTR [illegible] [illegible]
IN PERS [illegible] - COVER LTR - [illegible]

Definition of Terms

Unqualified Equipment: Equipment for which there is not adequate documentation to establish that this equipment will perform its intended functions in the relevant environment.

Significant Deficiency: Equipment determined to be unqualified and sufficient information cannot be developed during the inspection or shortly thereafter to achieve qualification and the inspector cannot make determination of qualifiability based on any other information available to the inspector.

Qualifiable Equipment: Equipment is not qualified but the inspector has sufficient basis (knowledge of additional test data and/or analysis) to conclude that the equipment can be fully qualified for the environment in which it is required to operate.

Operability: Reasonable assurance that the equipment will perform its safety function when called upon.

Note: Equipment does not have to be qualifiable to be considered operable. For example, based on test data/technical information it may be shown that equipment will be functional for sufficient time to perform its safety function even though it would be expected to fail later into the event. In this case, FMEA must be performed as a part of the operability argument.

#34

ATTENDANCE 6-1-88

NAME	REGION
JOHN BURDOIN	R-V
ALAN HERDT	R-II
DICK WILSON	HQ
STEVE ALEXANDER	HQ
AL JOHNSON	~~R IV~~
Johns Jaudon	R IV
Leonard Cheung	R I
J. J. Harrison	R III
Daniel Holody	R 1
Howard Wong	OE : HQ
George Hubbard	HQ
Anil S. Gautam	R III
ULDIS POTAPOVS	HQ
Bill Brach	HQ-VIB
Cliff Anderson	R-I
HAROLD WALKER	HQ-PSB
JACK KUDRICK	HQ-PSB

(20)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

August 6, 1987

MEMORANDUM FOR: Those on Attached List

FROM: James G. Partlow, Director
Division of Reactor Inspection and Safeguards
Office of Nuclear Reactor Regulation

SUBJECT: EQUIPMENT QUALIFICATION SEMINAR

The Division of Reactor Inspection and Safeguards is sponsoring a three day EQ training seminar at Sandia National Laboratories on August 26-28, 1987. This seminar is intended to provide specialized training for regional inspectors and headquarters staff who are involved in EQ activities. The topics covered will include a review of applicable regulatory requirements, inspection programs/procedures and a discussion of recently identified equipment-specific qualification problems and staff positions on generic issues. Classification of EQ deficiencies and application of the EQ enforcement policy will also be addressed. A preliminary agenda is enclosed. Based on previous discussions with the Region managers involved, we expect those inspectors and managers involved in the conduct of the first round EQ inspections and subsequent follow-up actions to attend. We regard this as an important forum for information exchange on the results of recent EQ inspections.

The seminar will be held in the Eldorado room of the Coronado Club which is located on Kirtland AFB grounds and will start at 8:30 am on Wednesday, August 26, 1987. The seminar will conclude by noon Friday, August 28, 1987. An optional tour of the Sandia EQ test facilities will be available Friday afternoon.

Please provide the names of individuals who will be participating in this training to U. Potapovs by no later than August 21, 1987 and indicate if they will participate in the laboratory tour. Individuals interested in the laboratory tour will need to provide their Social Security Numbers. For additional information, please contact U. Potapovs (492-9623).

Brian Grimes
for James G. Partlow, Director
Division of Reactor Inspection and Safeguards
Office of Nuclear Reactor Regulation

Enclosure: Agenda

EQUIPMENT QUALIFICATION SEMINAR
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO
AUGUST 26-28, 1987

AGENDA

Wednesday, August 26

1. Regulatory Requirements - overview

2. EQ Inspection Program

° Program scope/current status

° Program requirements

° Inspection Methodology
Pre-inspection Activities
Programmatic Areas

Equipment File reviews
Physical Inspection
Post-inspection activities

3. Technical Issues/Staff Positions

Environmental Considerations (LOCA, HELB, Submergence)
Qualification Methods
Equipment Similarity
Functional Performance Requirements
Aging considerations
Operating Time/Margin

Thursday, August 27

4. Equipment - Specific Qualification Issues
Limitorque Operators
Splices/terminations
Cable
Electrical Penetration Assemblies
Terminal Blocks
Solenoid Valves
Transmitters
Limit switches
Resistance Temp. Detectors
High Range Radiation Monitors
Motors

5. Regional Perspective

Team Leaders Role/Responsibilities
Regional Interfaces

Friday, August 28

Dispositioning of EQ Findings
Classification of EQ deficiencies
Operability Considerations
NRC Organizational Interfaces/responsibilities
EQ Enforcement Policy

The opening session of this seminar will be held at the Eldorado room of the Coronado Club which is located in Kirtland AFB. Enter the Base through Wyoming gate and proceed approximately 1/4 mile on the main road. Coronado Club will be on your right. You will need to get a vehicle pass at the Wyoming gate.

Recommended lodgings in the area are listed below:

Barcelona Court
900 Louisiana Blvd. NE
505-255-5566

Amberly Suite Hotel
7620 Pan American Frwy. NE
505-823-1300

Clarion Four Seasons Hotel
2500 Carlisle, NE
505-888-3311

August 6, 1987

List of Addressees

L. Shao, Director, Division of Engineering & Systems Technology
C. Rossi, Director, Division of Operational Events Assessment
W. Kane, Director, Division of Reactor Projects, RI
W. Johnston, Acting Director, Division of Reactor Safety, RI
L. Reyes, Director, Division of Reactor Projects, RII
A. Gibson, Director, Division of Reactor Safety, RII
C. Norelius, Director, Division of Reactor Projects, RIII
H. Miller, Acting Director, Division of Reactor Safety, RIII
E. Johnson, Director, Division of Reactor Safety and Projects, RIV
D. Kirsch, Director, Division of Reactor Safety and Projects, RV

DOCUMENT NAME:
EQ INSPECTION SLIDES

REQUESTOR'S ID:
STEVE

AUTHOR'S NAME:
ULDIS POTAPOVS

DOCUMENT COMMENTS:

(17)

EQ INSPECTION PROGRAM

DESCRIBED IN SECY-85-220 (JUNE 18, 1985)

START 1ST ROUND INSPECTIONS OCTOBER 1984, COMPLETE OCTOBER 1987.

OBJECTIVES:

- REVIEW LICENSEES' IMPLEMENTATION OF PROGRAM FOR MEETING 10 CFR 50.49 REQUIREMENTS.
- REVIEW LICENSEES' IMPLEMENTATION OF SER CORRECTIVE ACTION COMMITMENTS.
- REVIEW LICENSEES' IMPLEMENATION OF PROGRAM FOR MAINTAINING QUALIFIED STATUS OF EQUIPMENT DURING THE LIFE OF THE PLANT.
- PERFORM PHYSICAL INSPECTION OF EQUIPMENT TO DETERMINE THAT THE INSTALLATIONS AGREE WITH SER COMMITMENTS/QUALIFICATION REQUIREMENTS.

PROGRAM TRANSFERRED TO REGIONS AFTER MODULE DEVELOPMENT AND COMPLETION OF PILOT PHASE.

NRR TO PROVIDE TECHNICAL SUPPORT (STAFF AND CONSULTANT) AND TO COORDINATE OVERALL SCHEDULING.

EQ INSPECTION PROGRAM

CURRENT STATUS OF FIRST ROUND INSPECTIONS

(AUGUST 1987)

	RI	RII*	RIII	RIV	RV	TOTAL
SITES COMPLETED	15	8	16	5	5	49
SITES REMAINING	10	9	4	3	1	27

*DOES NOT INCLUDE SPECIAL PROJECTS SITES.

GENERIC LETTER 85-15 (AUGUST 6, 1985)

PROVIDES FOR CIVIL PENALTIES OF $5000 PER ITEM PER DAY WHICH MAY BE RETROACTIVELY IMPOSED:

> FOR NONCOMPLIANCE IDENTIFIED AFTER NOVEMBER 30, 1985, FOR EACH DAY A LICENSEE CLEARLY KNEW OR SHOULD HAVE KNOWN THAT EQUIPMENT QUALIFICATION WAS INCOMPLETE.

ESTABLISHED 3 MITIGATION FACTORS:

1. PROMPT IDENTIFICATION AND REPORTING.
2. BEST EFFORTS TO COMPLETE ENVIRONMENTAL QUALIFICATION BEFORE DEADLINE.
3. FULL COMPLIANCE WITHIN REASONABLE TIME.

GENERIC LETTER 85-15 (AUGUST 6, 1985)

DEFINES "UNQUALIFIED EQUIPMENT:"

"EQUIPMENT FOR WHICH THERE IS NOT ADEQUATE DOCUMENTATION TO ESTABLISH THAT THE EQUIPMENT WILL PERFORM ITS INTENDED FUNCTIONS IN THE RELEVANT ENVIRONMENT."

DEFINES "ITEM:"

"SPECIFIC TYPE OF ELECTRICAL EQUIPMENT, DESIGNATED BY MANUFACTURER AND MODEL WHICH IS REPRESENTATIVE OF ALL IDENTICAL EQUIPMENT IN A PLANT AREA EXPOSED TO THE SAME ENVIRONMENTAL SERVICE CONDITIONS."

GENERIC LETTER 86-15 (SEPTEMBER 22, 1986)

REQUIRES LICENSEES TO MAKE PROMPT DETERMINATION OF OPERABILITY WHEN UNQUALIFIED EQUIPMENT IS IDENTIFIED...

AND...

TO TAKE IMMEDIATE STEPS TO ESTABLISH A PLAN WITH A REASONABLE SCHEDULE TO CORRECT THE DEFICIENCY.

WRITTEN JUSTIFICATION FOR CONTINUED OPERATION (JCO) IS REQUIRED, BUT DOES NOT HAVE TO BE REVIEWED AND APPROVED BY NRC.

GENERIC LETTER 86-15 (SEPTEMBER 22, 1986)

R...IRES LICENSEES TO MAKE PROMPT DETERMINATION OF OPERABILITY WHEN UNQUALIFIED EQUIPMENT IS IDENTIFIED...

AND...

TO TAKE IMMEDIATE STEPS TO ESTABLISH A PLAN WITH A REASONABLE SCHEDULE TO CORRECT THE DEFICIENCY.

WRITTEN JUSTIFICATION FOR CONTINUED OPERATION (JCO) IS REQUIRED, BUT DOES NOT HAVE TO BE REVIEWED AND APPROVED BY NRC.

DEFINES "OPERABLE:"

- REASONABLE ASSURANCE THAT THE EQUIPMENT WILL PERFORM SAFETY FUNCTION(S) PRIOR TO FAILURE...

  AND...

- SUBSEQUENT FAILURE WILL NEITHER DEGRADE ANY OTHER SAFETY FUNCTION NOR MISLEAD THE OPERATOR.

FOR EQUIPMENT DEEMED INOPERABLE:

- INVOKES TECH SPECS FOR EQUIPMENT COVERED BY THEM.
- ALLOWS FOR OPERATION UNDER CERTAIN CONDITIONS IF INOPERABLE EQUIPMENT IS NOT UNDER TECH SPECS.

GENERIC LETTER 86-15 (SEPTEMBER 22, 1986)

TRANSMITS ENFORCEMENT GUIDANCE RELATED TO GL 85-15.

- APPLICATION OF "CLEARLY KNEW OR SHOULD HAVE KNOWN" TEST.

- TIME PERIOD FOR CIVIL PENALTY
  $500,000 PER ITEM CAP

- APPLICATION OF THE MITIGATION FACTORS
  $50,000 PER ITEM MINIMUM.

- OTHER ENFORCEMENT REGARDING VIOLATIONS OF EQ REQUIREMENTS IDENTIFIED AFTER NOVEMBER 30, 1985.

- IF VIOLATION EXISTED BEFORE DEADLINE, APPLY "CLEARLY KNEW OR SHOULD HAVE KNOWN" TEST.

- IF VIOLATION DOES NOT RELATE TO ACTION OR LACK OF ACTION BEFORE DEADLINE, USE NORMAL ENFORCEMENT.

SECY 87-32 (FEBRUARY 6, 1987)

PROPOSES THAT NO ENFORCEMENT ACTION BE TAKEN FOR CERTAIN VIOLATIONS I.E., UNQUALIFIED VALVE MOTOR OPERATOR INTERNAL WIRING.

COMMITS STAFF TO REVIEW LICENSEE SELF-IDENTIFIED EQ VIOLATIONS IN ACCORDANCE WITH ENFORCEMENT CRITERIA FOR EQ VIOLATIONS AND TAKE ENFORCEMENT ACTION AS APPROPRIATE.

EGM 87-02 (APRIL 10, 1987)

PROVIDES FURTHER GUIDANCE IN THE APPLICATION OF EQ ENFORCEMENT POLICY.

ESTABLISHES THRESHOLD FOR ESCALATED ENFORCEMENT:

THE QUALIFICATION DEFICIENCY IS NOT CONSIDERED SUFFICIENTLY SIGNIFICANT FOR ASSESSMENT OF CIVIL PENALTIES IF...

- SUFFICIENT DATA EXISTS OR IS DEVELOPED DURING THE INSPECTION TO DEMONSTRATE QUALIFICATION OF THE EQUIPMENT...

OR...

- BASED ON OTHER INFORMATION AVAILABLE TO THE INSPECTOR, THE SPECIFIC EQUIPMENT IS QUALIFIABLE FOR THE APPLICATION IN QUESTION.

EQ DEFICIENCIES

SEVERITY CLASSIFICATIONS

POTENTIALLY ESCALATED

A. SIGNIFICANT AUDITABILITY/PROGRAMMATIC PROBLEMS (GENERIC)

B. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION - EQUIPMENT QUALIFICATION STATUS INDETERMINATE.

SEVERITY LEVEL IV/V

C. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION, BUT EQUIPMENT CONSIDERED QUALIFIABLE.

D. SIGNIFICANT QUALIFICATION DEFICIENCIES CORRECTED DURING INSPECTION.

E. ISOLATED AUDITABILITY/PROGRAMMATIC PROBLEMS.

OPEN ITEMS

F. MINOR FILE DEFICIENCIES, WALKDOWN OBSERVATIONS.

EQ DEFICIENCIES

SEVERITY CLASSIFICATIONS

POTENTIAL ENFORCEMENT/UNRESOLVED ITEMS

POTENTIALLY ESCALATED

A. SIGNIFICANT AUDITABILITY/PROGRAMMATIC PROBLEMS (GENERIC)

B. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION - EQUIPMENT QUALIFICATION STATUS INDETERMINATE.

SEVERITY LEVEL IV/V

C. SIGNIFICANT QUALIFICATION DEFICIENCIES NOT RESOLVED DURING INSPECTION, BUT EQUIPMENT CONSIDERED QUALIFIABLE.

D. SIGNIFICANT QUALIFICATION DEFICIENCIES CORRECTED DURING INSPECTION.

E. ISOLATED AUDITABILITY/PROGRAMMATIC PROBLEMS.

OPEN ITEMS

F. MINOR FILE DEFICIENCIES, WALKDOWN OBSERVATIONS.

EQ DEFICIENCIES

TYPE CLASSIFICATION

A. Equipment not qualified/not on EQ list

B. Similarity of installed equipment to test sample not established in qualification file.

C. Similarity of installed equipment to test sample invalidated by improper Installation/Maintenance.

D. Qualification test parameters did not envelope plant environment.

E. Plant specific performance requirements for equipment not established/equipment performance not demonstrated.

F. Replacement equipment not upgraded to current requirements. (with no "Sound Reasons to the Contrary")

G. Significant errors in qualification analysis (qualified life calculations improperly performed, test anomalies not resolved, etc.).

EQ DEFICIENCIES

TYPE CLASSIFICATION

A. EQUIPMENT NOT QUALIFIED/NOT ON EQ LIST

B. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE NOT ESTABLISHED IN QUALIFICATION FILE.

C. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE INVALIDATED BY IMPROPER INSTALLATION/MAINTENANCE.

D. QUALIFICATION TEST PARAMETERS DID NOT ENVELOPE PLANT ENVIRONMENT.

E. PLANT SPECIFIC PERFORMANCE REQUIREMENTS FOR EQUIPMENT NOT ESTABLISHED/EQUIPMENT PERFORMANCE NOT DEMONSTRATED.

F. REPLACEMENT EQUIPMENT NOT UPGRADED TO CURRENT REQUIREMENTS.

G. SIGNIFICANT ERRORS IN QUALIFICATION ANALYSIS (QUALIFIED LIFE CALCULATIONS IMPROPERLY PERFORMED, TEST ANOMALIES NOT RESOLVED, ETC.).

EQ DEFICIENCIES

TYPE CLASSIFICATION

A. EQUIPMENT NOT QUALIFIED/NOT ON EQ LIST (§50.49(F),(D),(J))

B. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE NOT ESTABLISHED IN QUALIFICATION FILE. (§50.49(F)(2),(3)), (DOR-5.2.2), (0588 I & II - 5(2))

C. SIMILARITY OF INSTALLED EQUIPMENT TO TEST SAMPLE INVALIDATED BY IMPROPER INSTALLATION/MAINTENANCE. (SAME)

D. QUALIFICATION TEST PARAMETERS DID NOT ENVELOPE PLANT ENVIRONMENT. (§50.49(E)), (DOR-5.2.1), (0588 I & II - 2.2(4))

E. PLANT SPECIFIC PERFORMANCE REQUIREMENTS FOR EQUIPMENT NOT ESTABLISHED/EQUIPMENT PERFORMANCE NOT DEMONSTRATED. (§50.49(J)(2)),(DOR-5.2.5),(0588/I&II-2.1(3),2.2(7),(9),5(1))

F. REPLACEMENT EQUIPMENT* NOT UPGRADED TO CURRENT REQUIREMENTS (WITH NO "SOUND REASONS TO THE CONTRARY") (§50.49(L)/RG 1.89, REV 1).

G. SIGNIFICANT ERRORS IN QUALIFICATION ANALYSIS (QUALIFIED LIFE CALCULATIONS IMPROPERLY PERFORMED, TEST ANOMALIES NOT RESOLVED, ETC.). (§50.49(F),(J)), (DOR-5.1/5.3/VARIOUS), (0588 I & II - 2.1(4),2.4,5(1))

*NOTE: EQUIPMENT <u>PURCHASED</u> AFTER 2/22/83 (10CFR50.49 EFF. DATE), 10CFR50.49. §50.49(K) ALLOWS FOR NOT REQUALIFYING EQUIPMENT QUALIFIED UNDER DOR GUIDELINES (O.L. ≤ 5/23/80) OR NUREG-0588 (O.L. > 5/23/80) - CAT I (C.P. > 7/1/74) OR CAT II (C.P. < 7/1/74). SOME DOR & CAT II PLANTS COMMITTED TO NUREG-0588(I) FOR NUREG-0737 AND/OR RG 1.97 EQUIPMENT.

(§50.49(F),(D),(J))

(§50.49(F)(2),(3)),
DOR-5.2.2), (0588 I & II - 5(2))

(SAME)

(§50.49(E)), (DOR-5.2.1), (0588 I & II - 2.2(4))

(§50.49(J)(2)),(DOR-5.2.5),(0588/I&II-2.1(3),2.2(7),(9),5(1))

(§50.49(L)/RG 1.89,
REV 1).

(§50.49(F),(J)), (DOR-5.1/5.3/VARIOUS),
(0588 I & II - 2.1(4),2.4,5(1))

*NOTE: EQUIPMENT PURCHASED AFTER 2/22/83 (10CFR50.49 EFF. DATE), 10CFR50.49. §50.49(K) ALLOWS FOR NOT REQUALIFYING EQUIPMENT QUALIFIED UNDER DOR GUIDELINES (O.L. ≤ 5/23/80) OR NUREG-0588 (O.L. > 5/23/80) - CAT I (C.P. > 7/1/74) OR CAT II (C.P. < 7/1/74). SOME DOR & CAT II PLANTS COMMITTED TO NUREG-0588(I) FOR NUREG-0737 AND/OR RG 1.97 EQUIPMENT.

(18) 37l

EQUIPMENT QUALIFICATION SEMINAR
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO
AUGUST 26-28, 1987

AGENDA

Wednesday, August 26

UP Opening Remarks

1. Regulatory Requirements - overview

2. EQ Inspection Program

UP ~~° Program scope/current status~~

° Program requirements

TI 2515/76

Related Activities

° Inspection Methodology

Pre-inspection Activities

Programmatic Areas

Licensee Program/procedure

Maintenance/surveillance

Procurement/Replacement of equipment

EQML/Design change control

Training/QA/Audits

Equipment File reviews

File Selection/Depth of review

File Auditability

Physical Inspection

Equipment selection/scope

Inspection Technique

Equipment Traceability (cable)

Post-inspection activities

LUNCH

M.J. 3. Technical Issues/Staff Positions

Qualification Methods

Testing vs. Analysis

Equipment Similarity

Identical vs. Similar Equipment

Functional Performance Requirements

Aging considerations

SUBMERGENCE

Operating Time/Margin

Thursday, August 27

4. Equipment - Specific Qualification Issue

J.J. Limitorque Operators

S.A. Splices/terminations

M.J. Cable

RW Electrical Penetration Assemblies

M.J./S.A. Terminal Blocks

S.A. Solenoid Valves

S.A. Transmitters

S.A. Limit switches

M.J Resistance Temp. Detectors

M.J High Range Radiation Monitors

Motors

5. Regional Perspective

A.G. Team Leaders Role/Responsibilities

.G Regional Interfaces

Friday, August 28

Dispositioning of EQ Findings

UP Classification of EQ deficiencies

UP Operability Considerations

U.P NRC Organizational Interfaces/responsibilities

H W EQ Enforcement Policy

2.13.0

38

39 M

FRANKLIN RESEARCH CENTER

DIVISION OF ARVIN/CALSPAN

REFERENCE INFORMATION

FOR ENVIRONMENTAL QUALIFICATION INSPECTIONS

FRC REPORT NO. 5896-005-2

TECHNICAL REPORT

20TH & RACE STREETS PHILADELPHIA, PA 19103 TWX 710-670-1889 TEL (215) 448-1000

NRC Contract 05-83-215 FRC Project 5896-005

NRC Task No. TA-EL-205

REFERENCE INFORMATION

FOR ENVIRONMENTAL QUALIFICATION INSPECTIONS

FRC REPORT NO. 5896-005-2

Prepared for

Vendor Program Branch
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, DC 20555

NRC Task Leader: G. Hubbard FRC Task Leader: G. J. Toman

July 3, 1985

Prepared by:	Reviewed by:	Approved by:
[signature] Principal Author	[signature]	[signature] Department Director
Date: 7-3-85	Date: 7-3-85	Date: 7-3-85

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN
20th & RACE STREETS, PHILADELPHIA, PA 19103

CONTENTS

CONTENTS (Cont.)

REFERENCE INFORMATION FOR ENVIRONMENTAL QUALIFICATION INSPECTIONS

1.0 INTRODUCTION

This document provides background information and reference material for use in the performance of environmental qualification inspections of licensees. The topics described herein relate to the major concepts of environmental qualification inspection.

2.0 BACKGROUND

On May 23, 1980, the NRC issued Memorandum and Order CLI-80-21, specifying that licensees and applicants must meet the requirements set forth in the DOR Guidelines [1] and NUREG-0588 [2].

In mid-1981, the NRC issued Safety Evaluation Reports (SERs) on environmental qualification of safety-related electrical equipment to licensees of all operating plants. Where additional qualification information was required, the licensees were directed to respond to the NRC within 90 days of receipt of the SER.

In October 1981, the NRC authorized Franklin Research Center (FRC) to evaluate the licensees' resolutions of outstanding issues on equipment environmental qualification (EEQ) as discussed in the NRC SERs. The assignment was to review the qualification documentation in accordance with NRC criteria and to present the results in the form of a Technical Evaluation Report (TER) [3] for each of the 71 operating plants. The title for each TER was "Review of Licensees' Resolution of Outstanding Issues from NRC Equipment Environmental Qualification Safety Evaluation Reports" followed by the station name and unit number. Using the TERs, the NRC staff prepared Safety Evaluation Reports. Subsequently, the licensees responded with corrective action commitments and schedules. The environmental qualification inspection of the licensee determines that the corrective action commitments are being properly implemented. In addition, the inspection determines that each licensee has implemented a program that fulfills the requirements of 10CFR50.49 [4] for control of the qualification process. Included in the inspection process is the physical inspection of the installed equipment.

3.0 DESCRIPTION OF THE INSPECTION

There are four main areas of concern in the inspection: compliance of the licensee's program with 10CFR50.49, implementation of corrective actions regarding equipment requiring qualification, preservation of the qualification of equipment, and physical inspection of qualified equipment.

These four areas of concern have been incorporated into three inspection segments: procedural and programmatic inspection, documentation file inspection, and physical inspection. Methodology that may be used during the inspection to perform the various subtasks is given in this document.

4.0 DESCRIPTION AND USE OF EQ TER - REVIEW OF LICENSEES' RESOLUTION OF OUTSTANDING ISSUES FROM NRC EQUIPMENT ENVIRONMENTAL QUALIFICATION SAFETY EVALUATION REPORT

The TER [3] is useful both for determining the nature of the licensee's past problems with environmental qualification of equipment and for developing the list of devices to include in the inspection.

These TERs contain the results of the review of the licensee's harsh environment equipment qualification documentation with respect to the plant design environmental conditions.

Section 1 of the TER provides an introduction and defines the scope of the effort. Section 2 defines the review criteria. Section 3 describes the methodology used in the review. Section 4 of the TER contains the most useful information for the inspection and includes reviews of each piece of equipment as well as summaries of the overall plant review. Section 5 provides conclusions and specific overall concerns relating to the review. Section 6 contains the references upon which the review was based.

In Section 4.4 of the TER, the "Equipment Environmental Qualification Equipment Item Checksheet Index" provides a listing of the equipment evaluated along with the item numbers assigned to the equipment in the report (a similar listing with more detail concerning each device is given in Appendix B of the report). Table 4-1 provides a listing of equipment item numbers by TER evaluation result categories. These categories are:

I.A	Equipment Qualified
I.B	Equipment Qualification Pending Modification
II.A	Equipment Qualification Not Established
II.B	Equipment Not Qualified
II.C	Equipment Satisfies All Requirements Except Qualified Life or Replacement Schedule Justified
III.A	Equipment Exempt from Qualification
III.B	Equipment Not in the Scope of the Review
IV	Documentation Not Made Available.

The criteria for the use of these categories is contained in Section 3.3 of the TER. Equipment listed under Categories I.B, II.A, II.B, II.C, and IV should be considered for inclusion in the inspection sample list. Items in Category I.B can be inspected to see if the equipment has been modified or replaced as the licensee has indicated and that documentation has been provided to establish qualification of the currently installed equipment. Items in Categories II.A, II.C, and IV can be inspected to determine if new qualification, analysis, or documentation has been incorporated into the licensee's files. Items in Category II.B can be inspected to see if the devices have been modified and requalified or have been replaced with qualified devices.

Table 4-2 provides a further breakdown of the types of deficiencies noted. Table 4-3 provides a tabulation of deficiencies, the qualification category, and the corrective action that the licensee proposed at the time of submittal of the documentation for review.

Section 4.· also contains the individual reviews of each equipment item. The individual reviews describe the deficiencies noted in qualification methodology, and inadequacies of the qualification results with respect to plant requirements. These reviews provide the specific details that were used as the basis for the more general categories of deficiencies listed in the summary tables.

5.0 FAMILIARIZATION WITH REFERENCE DOCUMENTS

In addition to being familiar with the Technical Evaluation Report, the inspector should be familiar with the staff Safety Evaluation Report (which forwarded the TER and pinpointed specific staff concerns) and with the licensee's response to the SER. To allow review of the licensee's 10CFR50.49 program, the inspector should also be familiar with 10CFR50.49. The copy of 10CFR50.49 printed in Volume 48, No. 15 of the Federal Register may be particularly useful since much supplementary information concerning the scope of the rule is given. Sections b and c of 10CFR50.49 define the scope of the equipment covered and the types of design basis events to be considered. Sections d and j define the documentation that must be generated and maintained. Section e defines the environmental conditions to be evaluated, and Section f defines the allowable qualification methods. Section k states that the equipment already qualified to the DOR Guidelines [1] and NUREG-0588 [2] does not have to be requalified. Section l covers qualification of replacement equipment. Section g gives the time limit for completion of qualification efforts for operating plants.

If an evaluation of documentation is to be performed, the inspector should be familiar with the DOR Guidelines and IEEE Std 323-1971 [5]. A knowledge of Regulatory Guide 1.89, Rev.1 [6] and IEEE Std 323-1974 [7] is necessary for the evaluation of newer qualification results, as explained in the following note.

Note: The May 27, 1980 Commission Memorandum and Order, CLI-80-21, required replacement equipment to be qualified in accordance with NUREG-0588, Category I (IEEE Std 323-1974). Equipment replaced after February 22, 1983 must be qualified in accordance with 10CFR50.49 unless there are sound reasons to the contrary. Regulatory Guide 1.89, Rev. 1, June 1984 provides guidance for exceptions that may be taken for replacement equipment.

6.0 DETERMINATION OF COMPLETENESS OF EQUIPMENT LIST

This section is provided for use when an in-depth audit of the licensee's equipment list is to be performed.

6.1 GENERAL EVALUATION OF EQUIPMENT LIST

Table 1 contains lists of typical safety systems for BWR and PWR plants. Each of these systems contains some harsh environment equipment.

For the power plant under review, determine the titles in use for the systems. Then verify that the licensee's list of equipment requiring qualification contains at least one entry for each system. If no entry exists for any equipment in a system, verify that one of the following is true.

- o all system equipment is in a mild environment
- o all system equipment located in harsh environments is non-electrical in nature
- o all system equipment located in harsh environments is not required to be qualified by 10CFR50.49(b).

TABLE 1. TYPICAL SAFETY SYSTEMS FOR NUCLEAR POWER PLANTS*

1. BWR - Boiling Water Reactors

RPS	Reactor Protection System
PCIS	Primary Containment Isolation System
ECCS	Emergency Core Cooling System
HPCI	High Pressure Coolant Injection
ADS	Automatic Depressurization System
CS	Core Spray
LPCI	Low Pressure Coolant Injection
CGCS	Combustible Gas Control System
SGTS	Standby Gas Treatment System
MSIV	Main Steam Isolation Valves
RCIC	Reactor Core Isolation Cooling
SLCS	Stanby Liquid Control System
EPS	Emergency Power System
PAMS	Post-Accident Monitoring System
HVAC	Emergency Heating, Ventilation, and Air Conditioning Systems
RMS	Radiation Monitoring System

2. PWR - Pressurized Water Reactors

PRS	Reactor Protection System
PCIS	Primary Containment Isolation System
FWS	Feedwater System
AFWS	Auxiliary Feedwater System
CVCS	Chemical and Volume Control System
ESFAS	Engineered Safety Features Actuation System
CGCS	Combustible Gas Control System
SIS	Safety Injection System
CSS	Containment Spray System
SWS	Service Water System
CCW	Component Cooling Water
RMS	Radiation Monitoring System
EPS	Emergency Power System
HVAC	Emergency Heating, Ventilation, and Air Conditioning System
SDCS	Shutdown Cooling System
PAMS	Post-Accident Monitoring System

*This listing is generic in nature. Not all systems listed will be found at each plant, and system names may differ from plant to plant.

If no system equipment is found on the list and the system's equipment does not meet the above criteria, then a detailed review of the system should be performed as described in Section 6.3. Successful completion of the above effort indicates that equipment from each of the required systems has been included in the list of equipment requiring qualification.

6.2 EVALUATION OF THE CONTROL OF THE EQUIPMENT LIST

During the inspection, attention should be given to items that have been deleted from and added to the list of equipment requiring qualification. Items that have changed from one qualification status (e.g., from qualification not established to qualified) should also be reviewed. The first list of equipment that may be used is that contained in the TER, the second is the equipment list (Master List) submitted by the licensee to the NRC in May 1983, and the third is the licensee's present Master List. Comparison of entries on these lists will indicate those items that have been deleted and added. Special interest should be given to the items that have been deleted. The licensee's means of documenting the acceptability of deletion of an item from the list should be reviewed. The licensee's means of determining that the list is adequate and complete should also be reviewed.

6.3 DETAILED EVALUATION OF AN EQUIPMENT LIST

If it is deemed desirable, the list of equipment requiring qualification may be determined through the following steps. Since detailed evaluation of the equipment list is a large cumbersome task, it is recommended that the review be limited to one system or even a portion of a system.

a. From the piping and instrumentation diagram (P&ID), determine the major equipment that may require qualification, such as motors, motor operators for valves, and instrumentation. Since P&IDs will generally not contain details of harsh versus mild environment conditions, judgment should be used to limit the determination to harsh environment equipment.

b. For equipment found in item a above, review schematic and control diagrams (S&Cs) to determine additional interconnected devices, such as control and limit switches, terminal strips, and cable.

c. During the review of P&IDs and S&Cs, devices that support safety functions, such as providing cooling and non-safety-related devices whose failure could affect safety-related equipment, should be identified. Examples of non-safety-related devices of concern are associated circuits (non-safety circuits connected to Class IE power or which are in close proximity to safety-related circuits) and equipment protective devices, such as motor overload or over-temperature systems whose failure could prevent equipment from performing its safety function.

The list of equipment identified in the review of the P&IDs and S&Cs should then be compared to the licensee's Master List. A valid reason for the exclusion must be provided by the licensee for any component not on the Master List. Valid reasons include (1) the device is located in a mild environment, (2) the device is not required to be qualified by 10CFR50.49(b), (3) the device is non-electrical in nature, or (4) the device is non-safety related and its failure will not affect the safety function of the safety-related equipment (if such a device is electrically connected to a system whose components require qualification, a qualified electrical isolating device must be connected between the equipment requiring qualification and that which does not [see Regulatory Guide 1.75]).

7.0 SPECIFICATION OF PLANT CONDITIONS

a. To be in compliance with 10CFR50.49(d), the licensee must establish and maintain a file of plant conditions containing:

   1. Equipment performance specifications under the conditions expected to exist during and following design basis accidents.

   2. The voltage, frequency, load, and other electrical characteristics to which equipment will be subjected during and following design basis accidents.

   3. The environmental conditions at the location of the equipment including temperature, pressure, humidity radiation, chemicals, and submergence during and following design basis accidents.

b. Plant-specific harsh environment conditions at the location of the equipment must be contained in the file. The applicable design basis events that could result in a harsh environment, including flooding outside of containment, must have been considered in establishing these environments. The FSAR chapter containing the analysis of anticipated occurrences and postulated accidents may be used as a source of conditions to be considered in defining harsh environments. Flooding outside of containment may also occur from events other than high energy line breaks such as flooding of the plant site due to natural phenomena, inadvertent release of stored liquids, or fire protection system operation. These sources of flooding should have been considered in preparation of the specification of harsh environment conditions.

8.0 GUIDELINES FOR REVIEW OF ENVIRONMENTAL QUALIFICATION PROGRAM DOCUMENTS

8.1 Introduction

The following subsections provide an overview of the review process for evaluating the acceptability of a qualification program. This review model is most applicable to qualification programs performed to the requirements of IEEE Std 323-1974. The DOR Guidelines should be used as review guidance for those plants that were not committed to IEEE Std 323-71 or -74. Because environmental qualification is a detailed process and each qualification program tends to be unique, a detailed review methodology with specific criteria cannot be provided. The intent of this section is to provide an overview of the total review process. The evaluation of a qualification program includes review of the qualification specifications, the qualification plan and procedures, and the qualification report. Many qualification programs have been performed in which separate documents for the qualification plan and procedures do not exist. In reviewing such programs, the reviewer must determine that sufficient documentation exists to allow approval of the adequacy of methodology and of the results for the plant-specific application. Generally, a very detailed test report is necessary when no plan has been generated. As presented, the review appears as a stepwise operation; however, the overall effect of the multiple steps in the qualification process must be evaluated during the review to verify that the program is representative of the plant conditions and that the device is qualified for its application.

8.2 Licensee Review of Qualification Documentation

The licensee's qualification program must include provisions for the review and approval of qualification test and analysis documentation for plant-specific application and for determining that the qualification methodology is correct.

a. The licensee's procedural controls for review of qualification documentation must verify the following:

1. The installed equipment and associated auxiliary devices are identical to or adequately similar (see Section 8.4.2.1.b for a discussion of similarity) to that described in the qualification documentation.

2. The qualified mounting orientations and methods are applicable to the plant application.

3. The qualified connection and interface configurations are representative of the configurations used in the plant application.

4. Aging analyses and preconditioning methodology are adequate, and the established qualified life is valid for predicted normal and abnormal conditions. This entails verification that aging stresses such as thermal, radiation, and operational cycling have been adequately considered.

5. Acceptance criteria for performance of safety function used in the qualification program are adequate for the plant application.

6. The sequence of testing is conservative for the equipment and its application.

7. The qualified radiation dose encompasses both normal and accident radiation conditions and the dose types and dose rates have been considered to the extent practicable.

8. The adequacy of accident simulation methodology including:

   - adequacy of test setups
   - monitoring of test conditions
   - monitoring of specimen performance
   - calibration of test and performance monitoring equipment.

9. The adequacy of the accident simulation temperature, pressure, and humidity conditions for the predicted plant conditions.

10. As-te d spray rate, chemical composition, concentration, and duration adequately represent the predicted plant conditions.

11. The duration of the accident and post-accident conditions envelop plant application requirements.

12. Adequate margins exist between the as-qualified condition and the predicted accident conditions, for temperature, pressure, radiation, duration of conditions, and power source conditions.

13. Submergence testing, if required, has been acceptably performed.

14. Known significant synergistic effects have been accounted for in aging.

15. Any anomalies or deficiencies in the qualification program with regard to methodology or requirements of the plant-specific application are evaluated and analyzed for acceptability prior to approval of the qualification results.

16. Any analyses performed in lieu, or in support, of tests are adequate.

b. The personnel performing the licensee's reviews of the environmental qualification documentation should have training or experience in environmental qualification of equipment commensurate with the tasks performed.

8.3 Specification of Qualification Requirements

The licensee's qualification file must contain a qualification specification for each piece of equipment which sets forth the requirements for qualification. The qualification specification may be contained within a section of the purchase specification or may exist as a separate document. Verify that the following attributes have been specified for each type of equipment:

a. Safety Function - That function which the equipment is required to perform to ensure the safety of the plant.

Note: The safety function during normal service may be different from the safety function during accident service.

b. Environmental and Service Conditions - The conditions specified must include normal and abnormal temperature, pressure, radiation, humidity, voltage, frequency, vibration, operating cycles, and process conditions.

c. Accident Environment - The environmental conditions listed in b above must be defined for the equipment for design basis accident conditions.

d. Operability Requirements - The functional performance requirements for the device under normal, abnormal, and design basis accident conditions must be clearly defined (e.g., accuracy for a transmitter, stroketime for a valve actuator). The operability requirements may vary for normal, abnormal, and accident conditions. The period of time that the device must operate during accident conditions must also be specified.

8.4 Qualification Documentation

The following subsections concern the documentation that should be contained in the licensee's file for each type of installed equipment that requires qualification.

8.4.1 Qualification Plan

Note: For many older qualification programs, a separate qualification plan may not be available. If the plan is not available, a description of the qualification program sufficient to allow complete understanding of the tests and their bases must be contained in the qualification report. In cases where a qualification plan is not available, the plan attributes must be verified in the qualification report or other qualification documentation.

The qualification plan should contain the following information:

a. Equipment Identification - A detailed description of the device being qualified must be provided including manufacturer, model number, function, and ope tional capabilities.

b. Qualification Methodology - The plan must identify the method of qualification: type test, analysis, operating experience, or any combination of the three.

c. Aging Analysis - The plan must identify and analyze the expected effects of aging of the equipment during its installed life. Aging may be defined as the change with the passage of time of physical, chemical, or electrical properties of a device under design range operating conditions which may result in degradation of significant performance characteristics.

The various stresses which may result in degradation of equipment performance characteristics should be evaluated for their effect on the equipment. The analysis should identify and evaluate the materials of construction for the equipment. Aging stresses that should be accounted for include thermal degradation, humidity, pressure, radiation, and operational stresses. Guidance on thermal aging analyses may be found in EPRI-NP 1558 [8], Chapter 4. For radiation aging, the effects of different types of radiation (i.e., beta and gamma) should be addressed.

d. Synergistic Effects - Known synergistic effects must be addressed in the analysis of aging and accident conditions. Synergistic effects exist when the effect of combined stresses differs from the summation of the effects of separately applied stresses. Synergistic effects also result when the order of the application of stresses changes the resulting amount of degradation (e.g., for some materials, application of radiation aging before thermal aging produces more severe degradation than performing thermal aging first).

   Section C.5 of Regulatory Guide 1.89, Rev. 1, states that "synergistic effects known at this time are dose rate effects and effects resulting from the different sequence of applying radiation and (elevated) temperature."

e. Test Plan - Type testing is the method preferred by the NRC for qualifying equipment for harsh environment service. Type testing should be controlled through the use of a test procedure containing sufficient detail to allow test personnel to perform the tests properly. The test plan should contain the following:

   1. A description of the equipment to be tested including manufacturer, model number, connections, interfaces, and mounting.

   2. Description of test facilities including monitoring instrumentation and required accuracies.

   3. The service conditions to be simulated.

   4. Test procedures. (Note: The test procedures may be prepared as a separate document.)

   5. Test Sequence - The test sequence must follow the guidelines provided in IEEE Std 323-1974, Section 6.3.2.

6. Acceptance Criteria - The acceptance criteria should state the minimum functional capability of the equipment that is acceptable during normal, abnor- mal, and design basis accident testing.

7. Monitoring Requirements - The test plan must identify the equipment parameters to be monitored during testing. For devices susceptible to radiation or dose rate effects (e.g., electronics) monitoring during irradiation must be required for accident simulation.

8. Documentation Requirements - The requirements for documentation of the test results should be specified in the test plan.

8.4.2 Qualification Report

The qualification report documents the implementation of the qualification plan. The equipment specification and qualification plan are required for evaluation of the qualification report. The attributes for the qualification reports that are to be evaluated are divided into criteria for type testing, analysis, and operating experience.

8.4.2.1 <u>Type Testing</u>

The qualification documentation should contain the following information:

a. The description of the equipment tested (manufacturer, model number, function, and operational capabilities).

b. Similarity - When the description of the tested equipment does not completely agree with that of the installed equipment, an adequate similarity analysis must be included. The similarity analysis must address differences in materials, components, function, ratings, size and weight, and construction. The equipment must be manufactured by the same manufacturer under similar methods and processes. Note: The similarity analysis may be a separate document from the qualification report, but must be contained in the qualification documentation file.

c. Functional Testing - The results of the functional testing performed before, during, and after the qualification testing that show the performance requirements essential to the equipment's safety function have been met.

d. Aging Simulation - The aging simulation must adequately address the environmental and service conditions for the application of the device. Note: The aging evaluation may be contained in the qualification plan.

1. Thermal Aging - The time-related thermal degradation of non-metallic materials should be analyzed or simulated by accelerated means in the test program. The most common method of accelerating thermal aging degradation is exposure to an elevated temperature for a relatively short period. The relationship of the test temperature and duration to the life at normal temperatures is determined through use of the Arrhenius model.

   The Arrhenius model can be represented by the following equation:

$$t_a = t_s \exp \left[\frac{\phi}{k}\left(\frac{1}{T_a} - \frac{1}{T_s}\right)\right]$$

   where

   T_s = normal operating service temperature in degrees Kelvin

   T_a = accelerated thermal aging temperature in degrees Kelvin

   t_s = the age in days to be simulated for operation at the service temperature T_s

   t_a = accelerated thermal aging duration in days at the test temperature T_a

   ϕ = activation energy in eV

   k = Boltzmann's constant, 0.8617×10^{-4} eV/K

   The Arrhenius model assumes that, within a limited temperature range, the rate of thermal aging of each material is governed by a single degradation mechanism (related to the material's activation energy) and the absolute temperature. The rate of thermal aging increases exponentially as the activation energy is decreased and the absolute temperature increased. In applying the Arrhenius model, care must be taken to ensure that the activation energy used applies to both the specific material and to the degradation of the physical property of interest for that material (e.g., loss of tensile strength or loss of dielectric strength).

When evaluating the thermal aging program for normally energized equipment, it is important to identify any temperature rise from internal self-heating effects. For such devices, the internal temperature rise must be accounted for when performing aging calculations.

When a device is exposed to a temperature rise due to conduction or convection from a process line (e.g., RTD in a PWR hot leg line), the temperature rise due to the process conditions must also be accounted for in the aging analysis calculations.

2. Susceptibility to Vibration - If the qualification specification identifies non-seismic vibration as an environmental condition, this vibration must be addressed during qualification testing. Although no generally accepted model presently exists for accelerating the effects of vibration, testing for susceptibility to vibration should be performed when a vibration environment is specified.

3. Operational Aging - Operational aging is normally addressed by cycling a device to simulate the number of operations anticipated for the device over its installed life. The operations performed during qualification must represent the number of cycles and service conditions defined in the qualification specification. For continuous duty devices, operational aging may be addressed through thermal analysis and tests, and such analyses as bearing life evaluations.

4. Humidity - Practical models do not exist for quantitative acceleration of the effects of humidity on a device; however, an analysis or testing should have been performed to prove that the device is not susceptible to the effects of humidity. Note: LOCA withstand capability may be used as a means of indicating imperviousness to humidity.

5. Radiation - The device must have been exposed to the integrated dose anticipated over its installed life. Note: The radiation accident dose may be combined with the aging dose in a single irradiation applied prior to seismic testing.

e. Seismic Vibration - Although the review of seismic testing is outside the scope of the inspection, it should be verified that seismic testing or analysis was performed in the sequence of the environmental qualification of the equipment.

f. Design Basis Accident Simulation - The design basis accident conditions simulated in the test program must envelop the accident condition requirements of the qualification specification with adequate margins.

1. Accident Radiation - The equipment must have been exposed to the total integrated radiation dose defined in the qualification specification. For devices susceptible to malfunction during irradiation (e.g., electronics), the equipment must be operable and monitored during the simulation. Both gamma and beta radiation to which the equipment may be exposed must be addressed. Beta radiation may be addressed by shielding analysis, replacing it with an equal dose of gamma radiation, or by determining that it is small by comparison with the gamma dose (less than 10%, see Section 4.1 of the DOR Guidelines). The radiation dose applied should equal at least the specified dose plus a 10 percent margin. The margin need not be added if the specified dose contains a quantified margin of 10%.

2. Temperature Profile - The temperature profile must envelope the profile provided in the qualification specification and include adequate margin. Margin may be applied in various ways, including two applications of the initial transient and dwell at peak temperature, extension of the time at the peak temperature, and increase in the peak temperature (see IEEE Std 323-1974, Section 6.3.15). The time to reach the peak temperature for the initial transient(s) should not exceed the time specified in the equipment specification (i.e., the rate of temperature rise of the test reasonably represents the expected rate of rise of the postulated accident condition) unless justification has been provided.

3. Pressure Profile - The pressure profile attained during the type test must envelope the profile in the qualification specification and include margin (see IEEE Std 323-1974, Section 6.3.15).

4. Sprays - Chemical or demineralized sprays identified in the qualification specification must have been simulated during the type test and the duration and timing of application must be appropriate.

5. Humidity and Steam - The specified humidity and steam requirements must have been met during the accident simulation. Note: Application of high temperature without steam and humidity conditions is not acceptable.

6. Duration - The duration of the accident simulation should envelop the period required by the qualification specification. Acceleration (if any) of the long-term post-accident periods, at near normal environmental conditions, should be supported by analysis. Acceleration of accident conditions at high temperature and pressure is not represented by the Arrhenius model, unless activation energies were determined under conditions equivalent to those of the accident environment. It is important that the test chamber environment contains air unless oxidation effects are shown to be insignificant.

7. Test Setup - The apparatus used in performing the test must be described in the qualification report.

8. Monitoring Equipment - The equipment used in monitoring the environment of the chamber and the equipment under test must provide an adequate representation of test conditions (e.g., the temperature sensor is reasonably close to the test item to show the actual temperature experienced rather than the steam inlet temperature), must be calibrated, and must have the accuracy necessary to support the reported results. An adequate number of temperature sensors must have been used to obtain the representation of the temperature environment.

9. Connections/Interfaces - The mounting configuration, electrical and process connections, and interfaces must be adequately described so that the methods used can be duplicated in the plant application.

10. Deviations and Nonconformances - All deviations and nonconformances identified in the qualification test report or determinined during the application specific review must have been analyzed for their effect on the qualification of the equipment and the analysis made part of the qualification documentation file.

11. Periodic Maintenance and Refurbishment - The qualification documentation must specifically address any maintenance required to maintain the equipment in its qualified state. This may include replacement of components, lubrication requirements, periodic inspections of seals and gaskets, or complete equipment replacement.

8.4.2.2 Qualification by Operating Experience

The qualification report for qualification by operating experience must contain the following attributes:

a. The qualification specification

b. Comparison of required versus experienced operating environments and conditions and a comparison of equipment descriptions and functions. If the historical conditions do not completely envelop the required conditions, analysis and justification must be provided. Since no plants have experienced a LOCA/HELB after a significant period of operation, qualification for a LOCA/HELB environment cannot be based solely on operating experience.

c. Similarity Analysis - When the description of the tested equipment does not completely agree with that of the installed equipment, an adequate similarity analysis must be included. The similarity analysis must address differences in materials, components, function, ratings, size and weight, and construction. The equipment must be manufactured by the same manufacturer under similar methods and processes. Note: The similarity analysis may be a separate document from the qualification report, but must be contained in the qualification documentation file.

8.4.2.3 Qualification by Analysis

The qualification report for equipment qualification by analysis should contain the qualification specification and plan. The report must contain all analytical assumptions, mathematical models, and descriptions of computer programs used, along with the appropriate justification for their use. Qualification by analysis must be supported by partial type testing that validates the assumptions and models used. The type testing should be verified to be supportive of the analysis and pertinent to the equipment and operating conditions for which it is being applied.

9.0 PRESERVATION OF QUALIFICATION

For the environmental qualification to remain valid throughout the installed life of the equipment, the periodic maintenance, testing, and component replacement assumed as a basis for qualification testing or required by the manufacturer to maintain qualification must be performed on the device. In addition, the device must be replaced or refurbished at the end of its qualified life to assure proper operation under accident conditions as required by 10CFR50.49(e)(5).

The licensee must establish a program to determine the maintenance, testing, and component replacement requirements from qualification documentation. The program must include incorporation of these requirements into the periodic maintenance and test program. The program must identify and control replacement of the entire device at the end of its qualified life, replacement of subcomponents such as seals, O-rings, and diaphragms that may age more rapidly than the overall device, and lubrication and testing specified as the basis of the qualification or required by the manufacturer to maintain qualification.

Maintenance and testing requirements for preservation of qualification must be incorporated into periodic maintenance and testing procedures for the devices. These periodic maintenance and test procedures must be performed as scheduled.

The licensee must establish procedural controls that assure restoration of qualified equipment to the as-qualified condition following scheduled and non-routine maintenance or testing. The licensee's procedural controls must require replacement materials and components to be in-kind replacements or that their adequacy for use in qualified equipment be established through appropriate evaluation or testing.

Modifications to qualified devices and systems containing qualified devices must be evaluated and controlled such that the modified devices and systems retain their qualified status. The licensee's program must require changes of materials, and interfaces to be evaluated with regard to the qualification of the devices. New electrical equipment important to safety used in modifications must be added to the list of equipment requiring qualification and the equipment must be qualified in accordance with the licensee's established procedures. The procedures for control of plant modifications must evaluate all modifications for their effect upon qualified equipment. For example, addition of fire barriers must be evaluated for their change to local environments such that a significant temperature change does not occur in the vicinity of qualified equipment.

The licensee's procedural controls must require the evaluation and appropriate incorporation into maintenance testing program of information, such as IE Information Notices concerning equipment failures and notifications by vendors of modifications to maintenance requirements or of recognized equipment deficiencies or problems, affecting the preservation of qualification of equipment.

The licensee's program for evaluating failures and significant out-of-calibration conditions should require evaluation of the deficiency with regard to the qualified life of the equipment. Failure of qualified equipment in service prior to the end of its qualified life may indicate that environmental or service conditions beyond those simulated in the qualification program are affecting the equipment or that the aging simulation during qualification testing was inadequate. If the failure mode could affect multiple applications of a device, the qualification of the device should be reevaluated.

The licensee's program must require procurement documents for new and replacement equipment to specify the qualification requirements of 10CFR50.49 for equipment requiring qualification. Section C.6 of Regulatory Guide 1.89, Revision 1, provides guidance for specifying qualification of replacement parts to requirements other than 10CFR50.49. The licensee's procurement program may allow procurement documents to have different levels of detail for different types of replacement components. For in-kind replacement of materials and parts, the specification of normal and accident environ- ments need not be given and individual qualification testing of the materials and parts need not be required. However, the procurement documents for in-kind replacement must require materials and parts to be identical to those of the qualified equipment in which they will be used. Procurement documents for other than in-kind replacement materials, parts, and equipment must provide sufficient information to the vendor to allow qualification to be performed. (An alternative to this is licensee performance of qualification testing or analysis of components that are not in-kind replacements.)

10.0 PHYSICAL INSPECTION

The physical inspection of equipment requiring qualification will allow verification that qualification documentation is applicable to the installed equipment, that replacement and modification commitments have been implemented, and that the actual normal environments are in agreement with the specified normal environments. The physical inspection will also provide a general indication that the qualified status of equipment is being maintained and that all equipment requiring qualification has been included in the qualification program.

It is recognized that physical inspection will be limited by access conditions for the location of the equipment. When possible, the physical inspection should be scheduled during a major outage to allow access to harsh environment areas for which access is restricted during operation.

Prior to performance of the inspection, determine the following information for each of the selected devices:

- the device description, manufacturer, and model number as documented
- the safety function
- location of equipment
- the expected normal environment

- shielding or environment modification requirements
- mounting and orientation requirements
- qualified interfaces.

This information may be obtained from the licensee's system component evaluation work sheets (SCEW sheets), the environment specification, the corrective action commitments list (for shielding and environmental modification), and qualification documentation for the equipment.

During the physical inspection, the following tasks should be performed:

a. Determine that the description, manufacturer, and model number match those of the documentation.

b. Determine that the location agrees with the documented location. Particular care should be taken with respect to compartment level for areas subject to submergence.

c. Note environments and check for indications of temperature and moisture in excess of the expected environment. For areas with recorded temperatures (such as the drywell), the recorded temperature may be checked.

d. The method of mounting and orientation of the device should be compared with that described in the documentation.

e. List any auxiliary devices mounted on or attached to the equipment that could affect operation.

f. Determine that the interfaces for the equipment are the same as those qualified (i.e., process connection, electrical connections, and housing seals are the same as those qualified).

g. Determine that all external compartment covers, gaskets, and seals are in place and that they appear to be in good condition. Record the general external condition of equipment.

h. Determine that any required shielding or additional HVAC equipment is in place and functional. In the case of shielding, determine that it is adequately supported and does not have a potentially adverse effect on the equipment, such as limiting cooling.

i. Note whether equipment may be affected by conductive heat transfer from the process connection.

j. Determine if non-safety-related equipment is in close proximity to the qualified device such that its failure could compromise the safety function of the qualified device. Record its existence for further verification.

Following the physical inspection, differences between the as-installed condition and the as-documented conditions should be addressed by the licensee. Such conditions as unexpected elevated temperatures and humidity conditions, loose covers, and improper mounting must be corrected. The licensee should be requested to review all other similar equipment .

11.0 QUALIFICATION ATTRIBUTES OF TYPICAL ELECTRICAL EQUIPMENT IN SAFETY-RELATED APPLICATIONS IN HARSH ENVIRONMENTS

This section lists environmental qualification concerns relating to specific types of equipment located in harsh environments. These concerns are based on knowledge of the equipment and reviews of existing qualification documentation. The concerns have been divided into three categories: documentation, physical inspection, and preservation of qualification.

11.1 Electronic Transmitters (Pressure, Flow, Temperature)

11.1.1 Documentation

a. Seals for electronics housings are generally critical for correct operation under accident conditions to prevent steam and contaminants from affecting electronic circuitry. A review of documentation should indicate whether these seals must be replaced each time the housing is opened for calibration or maintenance and whether periodic replacement of the seal is required to maintain transmitter integrity.

b. Transmitters with similar model numbers may have large variations in ranges and applications. Care must be taken in determining the ranges and applications for which the transmitters are qualified. Manufacturers provide charts for interpretation of model numbers. The qualification documentation should explicitly indicate the models that are qualified.

c. Transmitter electronics may be susceptible to radiation dose and dose rate effects. Transmitters must have been shown to be operational during accident radiation simulation. Variations in accuracy during irradiation must be addressed by the qualification documentation.

Acceptability of such variations must be addressed for the application of the device.

d. The application of the transmitter may be limited by the process temperature. Qualification documentation or product literature should address these limits.

e. Mounting orientation may be limited to that of the qualification test or may require compensation of settings to account for variations in mounting unless the documentation justifies the applicability of the test mounting to other mounting methods.

11.1.2 Physical Inspection

a. The model number and range of the installed transmitter must be covered by the qualification documentation.

b. The process connection method used on the installed device should be the same as that described in the documentation file. Certain qualification tests indicated that particular types of process connections allowed leakage.

c. If non-seismic, non-hydrodynamic vibration from the process line or proximity to other equipment is identified on inspection, the qualification documentation should be reviewed to determine if such vibration was addressed.

d. Sealing of the transmitter housing is critical; therefore, all covers should be securely in place. All exposed seal edges should be in good condition and not be cracked or otherwise appear deteriorated.

e. If local indicators or other auxiliary devices are found to be connected to the transmitter, their qualification must be addressed in the documentation. Failure of such devices will generally prevent the transmitter from functioning.

f. The electrical connections and housing penetrations must be the same as those described in the documentation file. (Sealing of transmitter is generally critical to the function during accidents.)

g. If the transmitter is found to be below submergence level, the transmitter qualification must address submergence.

h. The mounting orientation and method must agree with the methods allowed by the qualification documentation.

i. The process temperature at the device must be within the limits prescribed by the manufacturer or the qualification of the device.

11.1.3 Preservation of Qualification

a. The maintenance and calibration intervals must agree with or be more conservative than those assumed in the qualification program.

b. If required, the maintenance and calibration procedures must address replacement of seals and gaskets upon removal of housing covers.

c. The calibration program should address evaluation of calibration drifts and zero shifts that are beyond the qualified limits. Such calibration drifts and zero shifts are, in reality, failures of the transmitters and should be evaluated to determine that the qualification program was adequate for the instrument or that conditions not considered during qualification have occurred during service.

11.2 Trip Switches

11.2.1 Documentation

a. During qualification, trip switch functional tests were sometimes performed by applying process test values equivalent to the setpoint, which does not demonstrate whether the switch would actuate at lower or higher pressures due to a setpoint or zero drift. Verify that during functional tests of the device, the actuation point was determined by gradually approaching the setpoint from a lower or higher simulated process condition as appropriate for the application (e.g., actuate on increasing pressure - test the device by approaching the setpoint from a lower pressure; actuate on decreasing pressure - test with process pressure approaching the setpoint from a higher pressure).

b. Trip switches, like transmitters, are subject to drift in their setpoints. Verify that the setpoint drift during qualification testing did not exceed the allowable tolerance defined in the acceptance criteria or that the setpoint drift recognized during qualification testing was evaluated for the plant-specific application.

c. Switches located below flood levels may be subject to electrical shorting as a result of in-leakage. For device locations susceptible to submergence, verify that testing was performed on the trip switch to verify its proper operation under submergence conditions.

11.2.2 Physical Inspection

a. During qualification testing, specific process and electrical connections are used. Verify that the connections used in the application are the same as those which were qualified or that justification for alternate connection systems have been provided.

11.2.3 Preservation of Qualification

a. Many gaskets and seals have limited qualified lifetimes. Identify any seals or gaskets with limited lifetimes in the qualification documentation, and verify that their periodic inspection/replacement is addressed in the maintenance program.

b. Most trip switches can maintain their setpoint accuracy for limited periods in use. Determine if the qualification documentation requires periodic adjustment or calibration of setpoints, and verify that these requirements are addressed in the maintenance program.

11.3 Radiation Monitors/Detectors

11.3.1 Documentation

a. Radiation monitors are normally qualified as a system which includes detectors, cables, electronics packages, and other accessories. Because the detectors provide very low-level signals, the qualification of the cable and connector system is critical to assure that the signal will be transmitted.

b. The electronics packages for the radiation monitors normally will not withstand a harsh environment (i.e., high temperature radiation or steam). Determine if the electronics must be located in a mild or relatively mild environment suitable for its qualification.

c. In qualifying radiation monitors, aging was sometimes considered for the entire device without addressing the materials of construction. Determine that the aging analyses identify the materials contained within the device and that the aging analysis is based on the most sensitive material.

d. Modifications were made to some radiation monitors during the testing to improve their performance without repeating steps of the testing already completed. Determine that evaluations of the effects of the modifications on the completed portions of the test program were performed.

e. Interconnecting cables used between detector assemblies and electronics packages should have been included in the qualification testing. Experience has shown that some of these cables require specific means of connection to ensure their integrity. Determine that the cable used during the testing is pre-qualified cable or that its qualification is completely covered by the test program and that any special connection methods are described in sufficient detail that they may be reproduced in the plant.

f. Radiation testing was not performed on some monitor systems. Determine that the effects of radiation were addressed for the equipment.

g. Determine that operation of the monitoring system was simulated during irradiation tests and that the system responded properly.

11.3.2 Physical Inspection

a. Manufacturers may have many different models under a generic equipment family. Determine that the devices installed in the plant are the qualified models.

b. As discussed in the documentation section, determine that the installed cable is qualified and that any special connections or seals used to qualify the equipment are used in the installation.

11.3.3 Preservation of Qualification

a. Many seals, gaskets, and electronic components have limited lifetimes in nuclear service. On the basis of the maintenance requirements in the qualification documentation, determine that the maintenance program addresses the periodic replacement/refurbishment of these components.

b. Since the qualification of the equipment may be dependent upon the cable and cable connection methods described in the qualification documentation, determine that the maintenance program establishes control over replacement/removal of interconnecting cabling.

11.4 Hydrogen Analyzers

11.4.1 Documentation

a. Qualification programs for some hydrogen analyzers did not include an analysis of materials used in the device. Determine that degradation as a result of aging was addressed for the materials used in the device.

b. Some analyzers were tested for limited accidents, and qualification to higher temperature and pressure profiles was not demonstrated. Determine that the accident profiles to which the device was qualified envelop the design conditions for the location of the equipment.

11.4.2 Physical Inspection

(No specific concerns)

11.4.3 Preservation of Qualification

a. Many of the components in the hydrogen analyzers have different qualified lifetimes and require replacement or refurbishment at different intervals. The maintenance program should be reviewed to determine that these intervals are addressed.

b. Some hydrogen analyzers require that the probes be vented for proper operation. Determine that periodic maintenance or inspection programs address this requirement.

11.5 Accelerometers/Acoustic Monitors

Note: Accelerometers and acoustic monitors are normally made up of three primary devices: a sensor, interconnecting cable, and an electronics package.

11.5.1 Documentation

a. Many different models exist for sensors and electronics packages. It should be established that the models used in the plant are identical to the qualified model or that a similarity analysis was provided to establish qualification of the installed devices.

b. Electronics packages for some devices are not suitable for use in a harsh environment. It should be determined that the environmental parameters for the location of the equipment are enveloped by the qualification documentation.

c. Accelerometers and acoustic monitor sensors may require unique installations. The installation requirements identified in the qualification documentation should be reviewed for verification during the physical inspection.

11.5.2 Physical Inspection

a. The qualification documentation may require sealing of cable connections to prevent electrical shorting due to in-leakage during accident conditions. The connections should be inspected to determine that required sealing has been implemented.

b. Determine that the mounting method agrees with the qualified method.

11.5.3 Preservation of Qualification

a. Where special sealing or mounting requirements are specified in the qualification documentation, determine that the maintenance program controls removal and replacement of connections and mounting to ensure that the methods required by the qualification program are preserved.

11.6 Motorized Valve Actuators

11.6.1 Documentation

a. Due to the time period over which many motorized valve actuators were manufactured, shipped, and installed, the materials used in the construction of the actuators have changed, most notably the organic components. Verification of the similarity of the installed device to the qualified device is necessary.

b. The aging analyses for many of the actuators may not have addressed all organic materials. The aging analysis should address the motor winding insulation, motor lead wire insulation, lubricants, and the organic materials in switches and seals.

c. Failures have occurred during qualification testing of motorized valve actuators, most notably due to chemical attack on some motor insulations and radiation-induced failures of motor brake assemblies. Most qualification attempts for motor brake assemblies resulted in failure. If a brake is used in the plant, determine that acceptable qualification results are available.

11.6.2 Physical Inspection

a. Determine if the motorized valve actuator contains a motor brake assembly. If it does, verify that the qualification documentation includes the brake. Most motor brakes have not been successfully qualified.

b. During qualification testing, water leakage into power and control terminal areas caused some valve actuator failures. Determine that the conduit connections for power to the motor and for control signals are sealed in accordance with the qualification documentation.

11.6.3 Preservation of Qualification

a. Although many motorized valve actuators have a qualified life claim of 40 years, the lubricants, seals, and gaskets require periodic replacement. Determine that the maintenance program makes provisions for addressing these items.

11.7 Solenoid Valves

11.7.1 Documentation

a. Continuous energization of a solenoid valve in service contributes significantly to the age-related degradation of elastomeric components as a result of temperature rises due to internal self-heating effects. Simply energizing the solenoid valve during a thermal aging simulation does not account for the increased degradation. Determine that the continuously energized solenoid valves have been identified and that the internal temperature rise due to self-heating effects has been included in Arrhenius calculations. For valves that were subjected to thermal aging while continuously energized, the internal temperature rises should be included in the calculation of the thermal aging temperature.

b. The materials used for seats and seals should be evaluated for their specific application. Viton has been shown to be susceptible to radiation damage when subjected to radiation doses exceeding approximately 20 Mrd and ethylene propylene terpolymer (EPDM) has been found to degrade as a result of air systems not being reasonably oil-free. Polyurethane has been shown to soften and adhere to other materials in the presence of water or oil at 140°F.

c. If the solenoid valve is required to perform a post-LOCA function, specified acceptance criteria for allowable seat leakage should be established. The seat leakage measured during qualification testing should be compared to these acceptance criteria to verify that the valves are adequately qualified for this service.

11.7.2 Physical Inspection

a. Solenoid valves contain many elastomeric components which are subject to thermal degradation. During the physical inspection, identify any solenoid valves mounted on or in close proximity to high-temperature process lines. For solenoid valves on or near high-temperature process lines, determine that the licensee has established the effect of the temperature rises (caused by conduction of heat from the process) on the qualified life of the components.

11.7.3 Preservation of Qualification

a. Most solenoid valves have limited qualified lifetimes and require periodic replacement of seats and seals or complete replacement of the device. Determine that the maintenance program requires periodic replacement of the seats and seals or of the entire valve, as required by the qualification program.

11.8 Limit Switches

11.8.1 Qualification Documentation

a. Some limit switches contain organic materials, such as nylon, which are susceptible to swelling when exposed to radiation. This swelling may affect contact position during irradiation, but may disappear within a few days of completion of irradiation. Verify that the limit switch was monitored and operated properly during the radiation simulation if materials that may swell have been used.

11.8.2 Physical Inspection

a. Most limit switches were tested with some type of conduit seal to prevent the entrance of moisture into the device. Determine that a qualified seal is used in the device installation.

b. Some manufacturers have qualified similar limit switches for different environments (i.e., inside containment or outside containment). During physical inspection, care must be taken to determine that the installed model is the model that is qualified for the environment associated with the location.

11.8.3 Preservation of Qualification

a. The seals and gaskets of most limit switches have been qualified for a limited lifetime. Determine that the maintenance program addresses their periodic replacement.

b. Some limit switches are qualified for only a 4- to 5-year period. Determine that replacement of such switches is included in the plant maintenance program.

c. Some limit switch manufacturers require periodic calibration of the device travel. Determine that the periodic calibration is addressed if required by the qualification documentation.

11.9 Electric Motors (Large, Continuous Duty)

11.9.1 Documentation

a. Bearing Lubrication - Lubrication of motor bearings is essential to continued motor operation. The qualification documentation should be reviewed to determine that the effects of radiation, aging, and contamination from accident environments and high temperature are addressed for lubricants. In addition recommended maintenance intervals for testing or replacement of the lubricant should be identified.

b. The motor winding-to-lead wire splice and lead* wire should be addressed in the qualification documentation and should be qualified with the motor, or separate qualification documentation should be available.

c. Larger motors may be equipped with accessory equipment such as motor or bearing cooling systems or heaters. These accessories must be evaluated to determine if accessories are required for motor operation or if their failure could inhibit proper motor operation. If the accessories are required for operation, they should be environmentally qualified; if they are not required, an analysis should be provided showing that failure of the accessory will not cause motor failure.

d. Protective devices required to prevent motor damage should be qualified for their application and proven not to remove the motor from service inappropriately.

e. The junction boxes and method of termination of external feed cables for the motors should be identified for comparison with the installed device.

f. The orientation of the motor reported in the qualification documentation should be identified. (Large motors are generally designed for one orientation only, and the qualification documentation should be specifically for that orientation.)

---

*The lead wire connects the winding to the motor terminals and is not to be confused with the external power feed cable for the motor.

g. The motor enclosure type used in qualification should be identified (e.g., sealed, open).

11.9.2 Physical Inspection

a. The motor nameplate data should be compared with the description in the qualification documentation. Pertinent information includes ratings, frame size, insulation class, operating voltage and current, and enclosure type.

b. The motor should be physically inspected for accessories such as cooling jackets, heaters, or lubrication systems (e.g., pumps, valves). (Note: Disassembly of the motor to determine the presence of accessories is not recommended.) If these accessories are installed, it should be established that the support equipment is qualified or analyzed for the effect of its failure.

c. The motor housing should be inspected for loose or missing cover plates and for housing sealing methods other than those described in the qualification documentation.

11.9.3 Maintenance Documentation

a. Determine that maintenance procedures address periodic testing or replacement of lubricants as specified in the qualification documentation or supplemental vendor maintenance requirements.

b. Determine that maintenance procedures address replacement of bearings when required.

c. For sealed motors, determine that periodic inspection or replacement of any organic seals is performed as required by the qualification documentation.

d. For motors with open housings, determine that periodic cleaning of motor internals is performed.

11.10 Electrical Cable

11.10.1 Documentation

a. The most significant problem in establishing qualification of installed cable has been establishing similarity to the cable that was tested. To demonstrate similarity in accordance with IEEE Std 383-1974 [9], the following attributes should be compared:

1. Conductor - material identification, size, stranding, coating

2. Insulation - material identification, thickness, method of application (should include curing method)

3. Assembly (multiconductor cable only) - number and arrangement of conductors, fillers, binders

4. Shielding - tapes, extrusions, braids or others

5. Covering - jacket or metallic armor (or both), material identification, thickness, method of application (should include curing method)

6. Characteristics - voltage and temperature rating (instrumentation cable - capacitance, attenuation, characterististic impedence, microphonics, insulation resistance)

7. Identification - manufacturer's trade name or catalogue number

Note: As a minimum, a manufacturer's statement or certification that the qualification documentation applies to the installed cable should be available (e.g., a statement that the material used and construction methods are the same as those of the qualification specimens).

b. In cable qualification tests, functional capability was monitored during accident simulation. Verify that the monitored parameter was of interest for the cable application (e.g., impedence for shielded instrument cable).

c. The qualified life evaluation of power cable should include consideration of temperature rise from the currents passing through the cable.

11.10.2 Physical Inspection

a. Determine, on the basis of the attributes listed in section B.10.1.a, that the installed cable is similar to the cable qualified. (Verification of manufacturing codes and numbers may be all that is possible.) Cable marking numbers should agree with qualification data. Obvious signs of mishandling or deterioration should be noted.

11.10.3 Preservation of Qualification

(No specific attributes)

11.11 Electrical Penetration Assemblies

11.11.1 Documentation

a. During qualification testing of electrical penetration assemblies, separate test specimens were used in many of the programs for different steps of the test sequence. Since this procedure is unacceptable, determine that a single specimen was exposed to all environmental influences required to demonstrate qualification.

b. Aging analyses for penetrations addressed only a limited number of materials. Determine that all non-metallic materials used in construction of the penetration were evaluated for the effects of age-related degradation.

c. Test documentation for penetrations has shown substantial reductions in insulation resistance during exposure to steam. For documentation where this is noted, determine that the licensee has evaluated the effects of the insulation resistance losses on instrumentation signals passing through the penetration.

11.11.2 Physical Inspection

a. Because of the many different types of modular and cellular penetrations in use, it should be verified that the qualified specimens are representative of the installed penetrations.

11.11.3 Preservation of Qualification

a. Because of the tendency of some epoxy and other organic materials to shrink with age, verify that the maintenance program addresses inspection and testing of penetrations to verify the adequacy of seal materials.

11.12 Splices, Terminations, and Connections

11.12.1 Documentation

a. During qualification testing, many terminations and connections were qualified while encased in external enclosures (e.g., junction boxes). Determine if the qualification documentation requires such enclosures to be installed.

11.12.2 Physical Inspection

a. Many different types and materials are in use for terminations, splices, and connections. Determine that the installed materials are those which were qualified.

b. Some manufacturers have placed limitations on the use of terminations, splices, and connections (e.g., two lug limit on a single terminal screw). Determine that any limitations established by the manufacturer are not exceeded in the installation.

c. Where qualification is predicated upon enclosure of the device, determine that the proper enclosure is provided.

11.12.3 Preservation of Qualification

a. Many manufacturers have provided explicit installation procedures for splices, terminations, and connectors. Determine that the maintenance program addresses use of these procedures for reinstallation after maintenance.

REFERENCES

1. "Guidelines for Evaluating Environmental Qualification of Class 1E Electrical Equipment in Operating Reactors," November 1979 (DOR Guidelines) issued as an Appendix to IE Bulletin 79-01B

2. NUREG-0588, Rev. 1, "Interim Staff Position on Environmental Qualification of Safety-Related Equipment," July 1981, USNRC, Washington, D.C.

3. Technical Evaluation Report (TER), "Review of Licensees' Resolution of Outstanding Issues from NRC Equipment Environmental Qualification Safety Evaluation Report." An individual TER for each operating power plant prepared by Franklin Research Center under NRC Contract 03-79-118

4. 10CFR50.49, "Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants," effective February 22, 1983, USNRC, Washington, D.C.

5. IEEE Std 323-1971, IEEE Trial-Use Standard: General Guide for Qualifying Class 1 Electric Equipment for Nuclear Power Generating Stations, The Institute of Electrical and Electronics Engineers, Inc., New York

6. Regulatory Guide 1.89, "Environmental Qualification of Certain Equipment Important to Safety for Nuclear Power Plants," Revision 1, June 1984, USNRC, Washington, D.C.

7. IEEE Std 323-1974, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, The Institute of Electrical and Electronics Engineers, Inc., New York

8. EPRI Report, NP-1558, S. P. Carfagno and R. J. Gibson, "A Review of Equipment Aging Theory and Technology," Electric Power Research Institute, Palo Alto, CA, September 1980

9. IEEE Std 383-1974, Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations, The Institute of Electrical and Electronics Engineers, Inc., New York

10. Regulatory Guide 1.75, "Physical Independence of Electric Systems," Revision 2, September 1978, USNRC, Washington, D.C.

APPENDIX A

REMEDIAL ACTIONS FOR TER FINDINGS

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN
20th & RACE STREETS, PHILADELPHIA, PA 19103

Appendix A: Remedial Actions for TER Findings

Section A.1 of this appendix provides a list of eight generic corrective actions which may be taken by the licensee to resolve deficiencies in the TER. Although the eight corrective actions are not the only possible resolutions of the deficiencies noted during the review, they are the most common. Any proposed corrective action must be evaluated for its applicability in demonstrating qualification of the installed equipment.

Section A.2 includes a brief description of the generic deficiency categories noted during the review of environmental qualification documentation submitted for 71 operating plants in response to IE Bulletin 79-01B. The reasons for citing a specific deficiency are included with each deficiency.

A.1 GENERIC CORRECTIVE ACTIONS

The corrective actions listed below can be applied almost universally to the deficiencies noted during the review.

a. Replacement of an unqualified device with a qualified device

b. Perform new qualification testing for existing equipment or acquire existing documentation

c. Perform similarity analysis to show that existing documentation applies to the installed device

d. Qualify by analysis (also extend qualification by analysis). In general, analysis should be used only for effects of one environmental parameter, since models for multiple effects generally do not exist

e. Modify service environment or provide shielding to allow use of existing documentation

f. Relocate equipment to mild environment

g. Exclude from scope of equipment requiring qualification (determination that equipment does not perform a safety function and its failure will not affect the performance of a safety function by another device)

h. Relocate equipment above flood level.

A.2 GENERIC DEFICIENCIES FROM TECHNICAL EVALUATION REPORT*

A.2.1 Documented Evidence of Qualification Inadequate

a. Basis for Issuance of Deficiency

1. Comp.ete absence of documentation

2. Documentation did not address environmental qualification

3. Documentation consisted of a test summary only, or

4. Documentation consisted of a certificate of compliance (no other documentation provided).

b. Possible Corrective Actions (from A.1)

a, b, f, g

A.2.2 Adequate Similarity Between Equipment and Test Specimen Not Established

a. Basis for Issuance of Deficiency

1. System Component Evaluation Work Sheet (SCEW sheet) did not contain sufficient information to describe installed equipment adequately

2. SCEW sheet identified a model number different from the model identified in the qualification documentation

3. Test report contained only device tag numbers and no equipment model numbers, or

4. Equipment subjected to qualification testing had special modifications for testing.

b. Possible Corrective Actions (from A.1)

a, b, c, f, g

A.2.3 Aging Degradation Not Evaluated Adequately and Qualified Life or Replacement Schedule Not Established

a. Basis for Issuance of Deficiency

*The TER deficiency descriptions were positive statements (e.g., "Document Evidence of Qualification Adequate"); here they are given in negative form for ease of interpretation of the deficiency.

1. Improper use of activation energies in aging calculations

2. Elimination of components subject to aging degradation from the aging evaluation without adequate justification

3. Extrapolation of manufacturer's recommended replacement intervals to forecast a longer qualified life without verifying the extrapolation with the manufacturer

4. Transposition and extrapolation of LOCA test environmental exposure to predict qualified life without adequate justification and analysis.

b. Possible Corrective Actions (from A.1)

a, b, c, d, e, f, g

A.2.4 Criteria Regarding Aging Simulation Not Satisfied

a. Basis for Issuance of Deficiency

1. Aging simulation not performed prior to accident simulation (applies only to NUREG-0588, Category I qualification programs).

b. Possible Corrective Actions (from A.1)

a, b, d, f, g

A.2.5 Criteria Regarding Temperature/Pressure Exposure Not Satisfied

a. Basis for Issuance of Deficiency

1. Peak Temperature Inadequate

(a) Peak temperature during qualification testing did not envelop plant-specific conditions.

2. Peak Pressure Inadequate

(a) Peak pressure during qualification testing did not envelop plant-specific conditions

(b) Accident testing was performed at ambient pressure.

3. Duration Inadequate

(a) Testing was performed for 1 or 2 hours at elevated pressure and temperature and used as evidence of qualification for longer periods

(b) Accident testing was performed for 30 days with a specified plant accident duration of up to one year.

4. Required Profile Enveloped Inadequately

(a) Failure of qualification results to envelop the specified accident conditions.

5. Steam Exposure Inadequate

(a) Accident testing was performed in an air oven at elevated temperature with no steam exposure.

b. Possible Corrective Actions (from A.1)

a, b, f, g

A.2.6 Criteria Regarding Spray Not Satisfied

a. Basis for Issuance of Deficiency

1. Chemical/demineralized water spray was not used during accident simulation

2. Material analyses were performed to qualify equipment for chemical spray without considering the increase in reactivity of the spray solution with increases in temperature or the effects of chemical plateout.

b. Possible Corrective Actions (from A.1)

a, b, d, e, f, g

A.2.7 Criteria Regarding Submergence Not Satisfied

a. Basis for Issuance of Deficiency

1. Equipment was identified as subject to submergence, but no testing was performed, or

2. Equipment was identified as completing protective actions prior to submergence, but no failure analysis was provided to demonstrate that the equipment's failure when submerged would not affect other class IE equipment.

b. Possible Corrective Actions (from A.1)

a, b, h or performance of a failure effects analysis (for case 2 above only)

A.2.8 Criteria Regarding Radiation Not Satisfied

a. Basis for Issuance of Deficiency

1. No test or analysis for radiation withstand capability was provided,

2. Equipment failed or exhibited aberrant behavior when exposed to radiation, or

3. Material analysis did not address the critical properties of the material for its application in the equipment.

b. Possible Corrective Actions (from A.1)

a, b, e, f, g

A.2.9 Criteria Regarding Test Sequence Not Satisfied

a. Basis for Issuance of Deficiency

1. Equipment containing materials subject to age-related degradation was not aged,

2. Equipment containing materials subject to radiation damage was not irradiated, or

3. Testing was performed on different test specimens with no one specimen subjected to entire test sequence.

b. Possible Corrective Actions (from A.1)

a, b, f, g

A.2.10 Inadequate Resolution of Test Specimen Failures or Severe Anomalies

a. Basis for Issuance of Deficiency

1. Equipment failed during initial phases of accident testing,

2. Equipment failed at longer term point of accident testing (e.g., failure at 15 days) with inadequate evaluation of the failure and accident simulation stresses

3. Significant instrument accuracy or setpoint changes were noted, or

4. Test equipment anomalies caused exposure transients with equipment failures resulting without adequate evaluation or analysis of event.

b. Possible Corrective Actions (from A.1)

a, b, f, g

Note: In cases where equipment failure occurred that was not attributable to inappropriate testing; replacement, relocation, or exclusion from scope should be used rather than retesting.

A.2.11 Criteria Regarding Instrument Accuracy Not Satisfied

a. Basis for Issuance of Deficiency

1. Instrumentation was tested, but no data on accuracy or setpoint and zero drift were provided, or

2. Data on accuracy and drift were provided with no evaluation of adequacy for the specific applications.

b. Possible Corrective Actions (from A.1)

a, b, f, g

(DRAFT)

REFERENCE INFORMATION
FOR ENVIRONMENTAL QUALIFICATION INSPECTIONS

FRC REPORT NO. 5896-005-2

NRC Contract 05-83-215
NRC Task No. TA-EL-205
FRC Project 5896-005

FRC Task Leader: G. J. Toman
NRC Task Leader: G. Hubbard

Prepared for

Vendor Program Branch
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, DC 20555

May , 1985

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN
20th & RACE STREETS, PHILADELPHIA, PA 19103

CONTENTS

CONTENTS (Cont.)

REFERENCE INFORMATION FOR ENVIRONMENTAL QUALIFICATION INSPECTIONS

1.0 INTRODUCTION

This document provides background information and reference material for use in performance of environmental qualification inspections. The information is contained in this document rather than in the Temporary Inspection because of its length. The topics described herein relate to the major concepts of equipment qualification inspection.

2.0 BACKGROUND

On May 23, 1980, the NRC issued Memorandum and Order CLI-80-21, specifying that licensees and applicants must meet the requirements set forth in the DOR Guidelines [1] and NUREG-0588 [2].

In mid-1981, the NRC issued Safety Evaluation Reports (SERs) on environmental qualification of safety-related electrical equipment to licensees of all operating plants. Where additional qualification information was required, the licensees were directed to respond to the NRC within 90 days of receipt of the SER.

In October 1981, the NRC authorized Franklin Research Center (FRC) to evaluate the licensees' resolutions of outstanding issues on equipment environmental qualification (EEQ) as discussed in the NRC SERs. The assignment was to review the qualification documentation in accordance with NRC criteria and to present the results in the form of a Technical Evaluation Report (TER) [3] for each of the 71 operating plants. The title for each TER was "Review of Licensees' Resolution of Outstanding Issues from NRC Equipment Environmental Qualification Safety Evaluation Reports" followed by the station name and unit number. Using the TERs, the NRC staff prepared Safety Evaluation Reports. Subsequently, the licensees responded with corrective action commitments and schedules. This inspection effort determines that the corrective action commitments are being properly implemented. In addition, the inspection determines that each licensee has implemented a program that fulfills the requirements of 10CFR50.49 [4] for control of the qualification process. Included in the inspection process is the physical inspection of the installed equipment.

3.0 DESCRIPTION OF THE INSPECTION

There are four main areas of concern in the inspection: compliance of the licensee's program with 10CFR50.49, implementation of corrective actions regarding equipment requiring qualification, preservation of the qualification of equipment, and physical inspection of qualified equipment.

These four areas of concern have been incorporated into three inspection segments: procedural and programmatic inspection, documentation file inspection, and physical inspection. Methodology that may be used during the inspection to perform the various subtasks is given in this document.

4.0 DESCRIPTION AND USE OF EQ TER - REVIEW OF LICENSEES' RESOLUTION OF OUTSTANDING ISSUES FROM NRC EQUIPMENT ENVIRONMENTAL QUALIFICATION SAFETY EVALUATION REPORT

The TER [3] is useful both for determining the nature of the licensee's past problems with environmental qualification of equipment and for developing the list of devices to include in the inspection.

These TERs contain the results of the review of the licensee's harsh environment equipment qualification documentation with respect to the plant design environmental conditions.

Section 1 of the TER provides an introduction and defines the scope of the effort. Section 2 defines the review criteria. Section 3 describes the methodology used in the review. Section 4 of the TER contains the most useful information for the inspection and includes reviews of each piece of equipment as well as summaries of the overall plant review. Section 5 provides conclusions and specific overall concerns relating to the review. Section 6 contains the references upon which the review was based.

In Section 4.4 of the TER, the "Equipment Environmental Qualification Equipment Item Checksheet Index" provides a listing of the equipment evaluated along with the item numbers assigned to the equipment in the report (a similar listing with more detail concerning each device is given in Appendix B of the report). Table 4-1 provides a listing of equipment item numbers by TER evaluation result categories. These categories are:

I.A	Equipment Qualified
I.B	Equipment Qualification Pending Modification
II.A	Equipment Qualification Not Established
II.B	Equipment Not Qualified
II.C	Equipment Satisfies All Requirements Except Qualified Life or Replacement Schedule Justified
III.A	Equipment Exempt from Qualification
III.B	Equipment Not in the Scope of the Review
IV	Documentation Not Made Available.

The criteria for the use of these categ es is contained in Section 3.3 of the TER. Equipment liste. under Categories I.B, II.A, II.B, II.C, and IV should be considered for inclusion in the inspection sample list. Items in Category I.B can be inspected to see if the equipment has been modified or replaced as the licensee has indicated. Items in Categories II.A and IV can be inspected to determine if new qualification, analysis, or documentation has been incorporated into the licensee's files. Items in Category II.B can be inspected to see if the devices have been modified and requalified or have been replaced with qualified devices.

Table 4-2 provides a further breakdown of the types of deficiencies noted. Table 4-3 provides a tabulation of deficiencies, the qualification category, and the corrective action that the licensee proposed at the time of submittal of the documentation for review.

Section 4.4 also contains the individual reviews of each equipment item. The individual reviews describe the deficiencies noted in qualification methodology, and inadequacies of the qualification results with respect to plant requirements. These reviews provide the specific details that were used as the basis for the more general categories of deficiencies listed in the summary tables.

5.0 FAMILIARIZATION WITH REFERENCE DOCUMENTS

In addition to being familiar with the Technical Evaluation Report, the inspector should be familiar with the staff Safety Evaluation Report (which forwarded the TER and pinpointed specific staff concerns) and with the licensee's response to the SER. To allow review of the licensee's 10CFR50.49 program, the inspector should also be familiar with 10CFR50.49. The copy of 10CFR50.49 printed in Volume 48, No. 15 of the Federal Register may be particularly useful since much supplementary information concerning the scope of the rule is given. Sections b and c of 10CFR50.49 define the scope of the equipment covered and the types of design basis events to be considered. Sections d and j define the documentation that must be generated and maintained. Section e defines the environmental conditions to be evaluated, and Section f defines the allowable qualification methods. Section k states that the equipment already qualified to the DOR Guidelines [1] and NUREG-0588 [2] does not have to be requalified. Section l covers qualification of replacement equipment. Section g states the time limit for completion of qualification efforts for operating plants.

If an evaluation of documentation is to be performed, the inspector should be fa[illegible]r with the DOR Guidelines and IEEE Std 323-1971 [5]. A k[illegible]ge of Regulatory Guide 1.89, Rev.1 [6] and IEEE Std 323-1[illegible]7] is necessary for the evaluation of newer qualification results.

Note: The May 27, 1980 Commission Memorandum and Order, CLI-80-21, required replacement equipment to be qualified in accordance with NUREG-0588, Category 1 (IEEE Std 323-1974). Equipment replaced after February 22, 1983 must be qualified in accordance with 10CFR50.49 unless there are sound reasons to the contrary. Regulatory Guide 1.89, Rev. 1, June 1984 provides guidance for exceptions that may be taken for replacement equipment.

6.0 DETERMINATION OF COMPLETENESS OF EQUIPMENT LIST

This section is provided for use when an in-depth audit of the licensee's equipment list is to be performed.

6.1 GENERAL EVALUATION OF EQUIPMENT LIST

Table 1 contains lists of typical safety systems for BWR and PWR plants. Each of these systems contains some harsh environment equipment.

For the power plant under review, determine the titles in use for the systems. Then verify that the licensee's list of equipment requiring qualification contains at least one entry for each system. If no entry exists for any equipment in a system, verify that one of the following is true.

- o all system equipment is in a mild environment
- o all system equipment located in harsh environments is non-electrical in nature
- o all system equipment located in harsh environments is not required to be qualified by 10CFR50.49(b).

If no system equipment is found on the list and the system's equipment does not meet the above criteria, then a detailed review of the system should be performed as described in Section E.2. Successful completion of the above effort indicates that equipment from each of the required systems has been included in the list of equipment requiring qualification.

6.2 EVALUATION OF THE CONTROL OF THE EQUIPMENT LIST

During the inspection, attention should be given to items that have been deleted from and added to the list of equipment requiring qualification. Items that have changed from one qualification status (e.g., from qualification not established to qualified) should also be reviewed. The first list of equipment that may be used is that contained in the TER, the second is the equipment list (Master List) supported by the licensee to the NRC in May 1983, and the third is the licensee's present Master List. Comparison of entries on these lists will indicate those items that have been deleted and added. Special interest should be given to the items that have been deleted. The licensee's means of documenting the acceptability of deletion of an item from the list should be reviewed. The licensee's means of determining that the list is adequate and complete should also be reviewed.

6.3 DETAILED EVALUATION OF AN EQUIPMENT LIST

If it is deemed desirable, the list of equipment requiring qualification may be determined through the following steps. Since detailed evaluation of the equipment list is a large cumbersome task, it is recommended that the review be limited to one system or even a portion of a system.

a. From the piping and instrumentation diagram (P&ID), determine the major equipment that may require qualification, such as motors, motor operators for valves, and instrumentation. Since P&IDs will generally not contain details of harsh versus mild environment conditions, judgment should be used to limit the determination to harsh environment equipment.

b. For equipment found in item a above, review schematic and control diagrams (S&Cs) to determine additional interconnected devices, such as control and limit switches, terminal strips, and cable.

TABLE 1. TYPICAL SAFETY SYSTEMS FOR NUCLEAR POWER PLANTS*

1. BWR - Boiling Water Reactors

RPS	Reactor Protection System
PCIS	Primary Containment Isolation System
ECCS	Emergency Core Cooling System
HPCI	High Pressure Coolant Injection
ADS	Automatic Depressurization System
CS	Core Spray
LPCI	Low Pressure Coolant Injection
CGCS	Combustible Gas Control System
SGTS	Standby Gas Treatment System
MSIV	Main Steam Isolation Valves
RCIC	Reactor Core Isolation Cooling
SLCS	Stanby Liquid Control System
EPS	Emergency Power System
PAMS	Post-Accident Monitoring System
HVAC	Emergency Heating, Ventilation, and Air Conditioning Systems
RMS	Radiation Monitoring System

2. PWR Pressurized Water Reactors

PRS	Reactor Protection System
PCIS	Primary Containment Isolation System
FWS	Feedwater System
AFWS	Auxiliary Feedwater System
CVCS	Chemical and Volume Control System
ESFAS	Engineered Safety Features Actuation System
CGCS	Combustible Gas Control System
SIS	Safety Injection System
CSS	Containment Spray System
SWS	Service Water System
CCW	Component Cooling Water
RMS	Radiation Monitoring System
EPS	Emergency Power System
HVAC	Emergency Heating, Ventilation, and Air Conditioning System
SDCS	Shutdown Cooling System
PAMS	Post-Accident Monitoring System

*This listing is generic in nature. Not all systems listed will be found at each plant, and system names may differ from plant to plant.

c. During the review of P&IDs and S&Cs, devices that support safety functions, such as providing cooling and non-safety-related devices whose failure could affect safety-related equipment, should be identified. Examples of non-safety-related devices of concern are associated circuits (non-safety circuits connected to Class IE power or which are in close proximity to safety-related circuits) and equipment protective devices, such as motor overload or over-temperature systems whose failure could prevent equipment from performing its safety function.

The list of equipment identified in the review of the P&IDs and S&Cs should then be compared to the lic nsee's Master List. A valid reason for the exclusion must be provided by the licensee for any component not on the Master List. Valid reasons include (1) the device is located in a mild environment, (2) the device is not required to be qualified by 10CFR50.49(b), (3) the device is non-electrical [illegible] ure, or (4) the device is non-safety related and its failure will not affect the safety function of the safety-related equipment (if such a device is electrically connected to a system whose components require qualification, a qualified electrical isolating device must be connected between the equipment requiring qualification and that which does not [see Regulatory Guide 1.75]).

7.0 SPECIFICATION OF PLANT CONDITIONS

a. To be in compliance with 10CFR50.49(d), the licensee must establish and maintain a file of plant conditions containing:

   1. Equipment performance specifications under the conditions expected to exist during and following design basis accidents.

   2. The voltage, frequency, load, and other electrical characteristics to which equipment will be subjected during and following design basis accidents.

   3. The environmental conditions at the location of the equipment including temperature, pressure, humidity, radiation, chemicals, and submergence during and following design basis accidents.

b. Plant-specific harsh environment conditions at the location of the equipment must be contained in the file. The applicable design basis events that could result in a harsh environment, including flooding outside of containment, must have been considered in establishing these environments. The FSAR chapter containing the analysis of anticipated occurrences and postulated accidents may be used as a source of conditions to be considered in defining harsh environments. Flooding outside of containment may also occur from events other than high energy line breaks such as flooding of the plant site due to natural phenomena, inadvertent release of stored liqui or fire protection system operation. These sources of looding should have been considered in preparation of the specification of harsh environment conditions.

8.0 GUIDELINES FOR REVIEW OF ENVIRONMENTAL QUALIFICATION PROGRAM DOCUMENTS

8.1 Introduction

The following subsections provide an overview of the review process for evaluating the acceptability of a qualification program. This review model is most applicable to qualification programs performed to the requirements of IEEE Std 323-1974. The DOR Guidelines should be used as review guidance for those plants that were not committed to IEEE Std 323-71 or -74. Because environmental qualification is a detailed process and each qualification program tends to be unique, a detailed review methodology with specific criteria cannot be provided. The intent of this section is to provide an overview of the total review process. The evaluation of a qualification program includes review of the qualification specifications, the qualification plan and procedures, and the qualification report. Many qualification programs have been performed in which separate documents for the qualification plan and procedures do not exist. In reviewing such programs, the reviewer must determine that sufficient documentation exists to allow approval of the adequacy of methodology and of the results for the plant-specific application. Generally, a very detailed test report is necessary when no plan has been generated. As presented, the review appears as a stepwise operation; however, the overall effect of the multiple steps in the qualification process must be evaluated during the review to verify that the program is representative of the plant conditions and that the device is qualified for its application.

8.2 Licensee Review of Qualification Documentation

The licensee's qualification program must include provisions for the review and approval of qualification test and analysis documentation for plant-specific application and for determining that the qualification methodology is correct.

a. The licensee's procedural controls for review of qualification documentation must verify the following:

1. The installed equipment and associated auxiliary devices are identical to or adequately similar (see Section 8.4.2.1.b for a discussion of similarity) to that described in the qualification documentation.

2. The qualified mounting orientations and methods are applicable to the plant application.

3. The qualified connection and interface configurations are representative of the configurations used in the plant application.

4. Aging analyses and preconditioning methodology are adequate, and the established qualified life is valid for predicted normal and abnormal conditions. This entails verification that aging stresses such as thermal, radiation, and operational cycling have been adequately considered.

5. Acceptance criteria for performance of safety function used in the qualification program are adequate for the plant application.

6. The sequence of testing is conservative for the equipment and its application.

7. The qualified radiation dose encompasses both normal and accident radiation conditions and the dose types and dose rates have been considered to the extent practicable.

8. The adequacy of accident simulation methodology including:

   - adequacy of test setups
   - monitoring of test conditions
   - monitoring of specimen performance
   - calibration of test and performance monitoring equipment.

9. The adequacy of the accident simulation temperature, pressure, and humidity conditions for the predicted plant conditions.

10. As-tested spray rate, chemical composition, concentration, and duration adequately represent the predicted plant conditions.

11. The duration of the accident and post-accident conditions envelop plant application requirements.

12. Adequate margins exist between the as-qualified condition and the predicted accident conditions, for temperature, pressure, radiation, duration of conditions, and power source conditions.

13. Submergence testing, if required, has been acceptably performed.

14. Known significant synergistic effects have been accounted for in aging.

15. Any anomalies or deficiencies in the qualification program with regard to methodology or requirements of the plant-specific application are evaluated and analyzed for acceptability prior to approval of the qualification results.

16. Any analyses performed in lieu, or in support, of tests are adequate.

b. The personnel performing the licensee's reviews of the environmental qualification documentation should have training or experience in environmental qualification of equipment commensurate with the tasks performed.

8.3 Specification of Qualification Requirements

The licensee's qualification file must contain a qualification specification for each piece of equipment which sets forth the requirements for qualification. The qualification specification may be contained within a section of the purchase specification or may exist as a separate document. Verify that the following attributes have been specified for each type of equipment:

a. Safety Function - That function which the equipment is required to perform to ensure the safety of the plant.

Note: The safety function during normal service may be different from the safety function during accident service.

b. Environmental and Service Conditions - The conditions specified must include normal and abnormal temperature, pressure, radiation, humidity, voltage, frequency, vibration, operating cycles, and process conditions.

c. Accident Environment - The environmental conditions listed in b above must be defined for the equipment for design basis accident conditions.

d. Operability Requirements - The functional performance requirements for the device under normal, abnormal, and design basis accident conditions must be clearly defined (e.g., accuracy for a transmitter, stroketime for a valve actuator). The operability requirements may vary for normal, abnormal, and accident conditions. The period of time that the device must operate during accident conditions must also be specified.

8.4 Qualification Documentation

The following subsections concern the documentation that should be contained in the licensee's file for each type of installed equipment that requires qualification.

8.4.1 Qualification Plan

Note: For many older qualification programs, a separate qualification plan may not be available. If the plan is not available, a description of the qualification program sufficient to allow complete understanding of the tests and their bases must be contained in the qualification report. In cases where a qualification plan is not available, the plan attributes must be verified in the qualification report or other qualification documentation.

The qualification plan should contain the following information:

a. Equipment Identification - A detailed description of the device being qualified must be provided including manufacturer, model number, function, and operational capabilities.

b. Qualification Methodology - The plan must identify the method of qualification: type test, analysis, operating experience, or any combination of the three.

c. Aging Analysis - The plan must identify and analyze the expected effects of aging of the equipment during its installed life. Aging may be defined as the change with the passage of time of physical, chemical, or electrical properties of a device under design range operating conditions which may result in degradation of significant performance characteristics.

The various stresses which may result in degradation of equipment performance characteristics should be evaluated for their effect on the equipment. The analysis should identify and evaluate the materials of construction for the equipment. Aging stresses that should be accounted for include thermal degradation, humidity, pressure, radiation, and operational stresses. Guidance on thermal aging analyses may be found in EPRI-NP 1558 [8], Chapter 4. For radiation aging, the effects of different types of radiation (i.e., beta and gamma) should be addressed.

d. Synergistic Effects - Known synergistic effects must be addressed in the analysis of aging and accident conditions. Synergistic effects exist when the effect of combined stresses differs from the summation of the effects of separately applied stresses. Synergistic effects also result when the order of the application of stresses changes the resulting amount of degradation (e.g., for some materials, application of radiation aging before thermal aging produces more severe degradation than performing thermal aging first).

   Section C.5 of Regulatory Guide 1.89, Rev. 1, states that "synergistic effects known at this time are dose rate effects and effects resulting from the different sequence of applying radiation and (elevated) temperature."

e. Test Plan - Type testing is the method preferred by the NRC for qualifying equipment for harsh environment service. Type testing should be controlled through the use of a test procedure containing sufficient detail to allow test personnel to perform the tests properly. The test plan should contain the following:

   1. A description of the equipment to be tested including manufacturer, model number, connections, interfaces, and mounting.

   2. Description of test facilities including monitoring instrumentation and required accuracies.

   3. The service conditions to be simulated.

   4. Test procedures. (Note: The test procedures may be prepared as a separate document.)

   5. Test Sequence - The test sequence must follow the guidelines provided in IEEE Std 323-1974, Section 6.3.2.

6. Acceptance Criteria - The acceptance criteria should state the minimum functional capability of the equipment that is acceptable during normal, abnor- mal, and design basis accident testing.

7. Monitoring Requirements - The test plan must identify the equipment parameters to be monitored during testing. For devices susceptible to radiation or dose rate effects (e.g., electronics) monitoring during irradiation must be required for accident simulation.

8. Documentation Requirements - The requirements for documentation of the test results should be specified in the test plan.

8.4.2 Qualification Report

The qualification report documents the implementation of the qualification plan. The equipment specification and qualification plan are required for evaluation of the qualification report. The attributes for the qualification reports that are to be evaluated are divided into criteria for type testing, analysis, and operating experience.

8.4.2.1 <u>Type Testing</u>

The test report should contain the following information:

a. The description of the equipment tested (manufacturer, model number, function, and operational capabilities).

b. Similarity - When the description of the tested equipment does not completely agree with that of the installed equipment, an adequate similarity analysis must be included. The similarity analysis must address differences in materials, components, function, ratings, size and weight, and construction. The equipment must be manufactured by the same manufacturer under similar methods and processes. Note: The similarity analysis may be a separate document from the qualification report, but must be contained in the qualification documentation file.

c. Functional Testing - The results of the functional testing performed before, during, and after the qualification testing that show the performance requirements essential to the equipment's safety function have been met.

d. Aging Simulation - The aging simulation must adequately address the environmental and service conditions for the application of the device. Note: The aging evaluation may be contained in the qualification plan.

1. Thermal Aging - The time-related thermal degradation of non-metallic materials should be analyzed or simulated by accelerated means in the test program. The most common method of accelerating thermal aging degradation is exposure to an elevated temperature for a relatively short period. The relationship of the test temperature and duration to the life at normal temperatures is determined through use of the Arrhenius model.

   The Arrhenius model can be represented by the following equation:

$$t_a = t_s \exp \left[\frac{\phi}{k}\left(\frac{1}{T_a} - \frac{1}{T_s}\right)\right]$$

   where

   T_s = normal operating service temperature in degrees Kelvin

   T_a = accelerated thermal aging temperature in degrees Kelvin

   t_s = the age in days to be simulated for operation at the service temperature T_s

   t_a = accelerated thermal aging duration in days at the test temperature T_a

   ϕ = activation energy in eV

   k = Boltzman's constant, 0.8617×10^{-4} eV/K

   The Arrhenius model assumes that, within a limited temperature range, the rate of thermal aging of each material is governed by a single degradation mechanism (related to the material's activation energy) and the absolute temperature. The rate of thermal aging increases exponentially as the activation energy is decreased and the absolute temperature increased. In applying the Arrhenius model, care must be taken to ensure that the activation energy used applies to both the specific material and to the degradation of the physical property of interest for that material (e.g., loss of tensile strength or loss of dielectric strength).

When evaluating the thermal aging program for normally energized equipment, it is important to identify any temperature rise from internal self-heating effects. For such devices, the internal temperature rise must be accounted for when performing aging calculations.

When a device is exposed to a temperature rise due to conduction or convection from a process line (e.g., RTD in a PWR hot leg line), the temperature rise due to the process conditions must also be accounted for in the aging analysis calculations.

2. Susceptibility to Vibration - If the qualification specification identifies non-seismic vibration as an environmental condition, this vibration must be addressed during qualification testing. Although no generally accepted model presently exists for accelerating the effects of vibration, testing for susceptibility to vibration should be performed when a vibration environment is specified.

3. Operational Aging - Operational aging is normally addressed by cycling a device to simulate the number of operations anticipated for the device over its installed life. The operations performed during qualification must represent the number and service conditions defined in the qualification specification.

4. Humidity - Practical models do not exist for quantitative acceleration of the effects of humidity on a device; however, an analysis or testing should have been performed to prove that the device is not susceptible to the effects of humidity. Note: LOCA withstand capability may be used as a means of indicating impreviousness to humidity.

5. Radiation - The device must have been exposed to the integrated dose anticipated over its installed life. Note: The radiation accident dose may be combined with the aging dose in a single irradiation applied prior to seismic testing.

e. Seismic Vibration - Although the review of seismic testing is outside the scope of the inspection, it should be verified that seismic testing or analysis was performed in the sequence of the environmental qualification.

f. Design Basis Accident Simulation - The design basis accident conditions simulated in the test program must envelop the accident condition requirements of the qualification specification with adequate margins.

1. Accident Radiation - The equipment must have been exposed to the total integrated radiation dose defined in the qualification specification. For devices susceptible to malfunction during irradiation (e.g., electronics), the equipment must be operable and monitored during the simulation. Both gamma and beta radiation to which the equipment may be exposed must be addressed. Beta radiation may be addressed by shielding analysis, replacing it with an equal dose of gamma radiation, or by determining that it is small by comparison with the gamma dose (less than 10%, see Section 4.1 of the DOR Guidelines). The radiation dose applied should equal at least the specified dose plus a 10 percent margin. The margin need not be added if the specified dose contains a quantified margin of 10%.

2. Temperature Profile - The temperature profile must envelope the profile provided in the qualification specification and include adequate margin. Margin may be applied in various ways, including two applications of the initial transient and dwell at peak temperature, extension of the time at the peak temperature, and increase in the peak temperature (see IEEE Std 323-1974, Section 6.3.15). The time to reach the peak temperature for the initial transient(s) should not exceed the time specified in the equipment specification (i.e., the rate of temperature rise of the test reasonably represents the expected rate of rise of the postulated accident condition) unless justification has been provided.

3. Pressure Profile - The pressure profile attained during the type test must envelope the profile in the qualification specification and include margin (see IEEE Std 323-1974, Section 6.3.15).

4. Sprays - Chemical or demineralized sprays identified in the qualification specification must have been simulated during the type test and the duration and timing of application must be appropriate.

5. Humidity and Steam - The specified humidity and steam requirements must have been met during the accident simulation. Note: Application of high temperature without steam and humidity conditions is not acceptable.

6. Duration - The duration of the accident simulation should envelop the period required by the

qualification specification. Acceleration (if any) of the long-term, near normal environment, post-accident periods should be supported by analysis. Acceleration of accident conditions at high temperature and pressure is not represented by the Arrhenius model, unless activation energies were determined under conditions equivalent to those of the accident environment. It is important that the test chamber environment contains air unless oxidation effects are shown to be insignificant.

7. Test Setup - The apparatus used in performing the test must be described in the qualification report.

8. Monitoring Equipment - The equipment used in monitoring the environment of the chamber and the equipment under test must provide an adequate representation of test conditions (e.g., the temperature sensor is reasonably close to the test item to show the actual temperature experienced rather than the steam inlet temperature), must be calibrated, and must have the accuracy necessary to support the reported results. An adequate number of temperature sensors must have been used to obtain the representation of the temperature environment.

9. Connections/Interfaces - The mounting configuration, electrical and process connections, and interfaces must be adequately described so that the methods used can be duplicated in the plant application.

10. Deviations and Nonconformances - All deviations and nonconformances identified in the qualification report must have been analyzed for their effect on the qualification of the equipment.

11. Periodic Maintenance and Refurbishment - The qualification documentation must specifically address any maintenance required to maintain the equipment in its qualified state. This may include replacement of components, lubrication requirements, periodic inspections of seals and gaskets, or complete equipment replacement.

8.4.2.2 <u>Qualification by Operating Experience</u>

The qualification report for qualification by operating experience must contain the following attributes:

a. The qualification specification

b. Comparison of required versus experienced operating environments and conditions and a comparison of equipment descriptions and functions. If the historical conditions do not completely envelop the required conditions, analysis and justification must be provided. Since no plants have experienced a LOCA/HELB after a significant period of operation, qualification for a LOCA/HELB environment cannot be based solely on operating experience.

8.4.2.3 Qualification by Analysis

The qualification report for equipment qualification by analysis should contain the qualification specification and plan. The report must contain all analytical assumptions, mathematical models, and descriptions of computer programs used, along with the appropriate justification for their use. Qualification by analysis must be supported by partial type testing that validates the assumptions and models used. The type testing should be verified to be supportive of the analysis and pertinent to the equipment and operating conditions for which it is being applied.

9.0 PRESERVATION OF QUALIFICATION

For the environmental qualification to remain valid throughout the installed life of the equipment, the periodic maintenance, testing, and component replacement assumed as a basis for qualification testing must be performed on the device. In addition, the device must be replaced at the end of its qualified life to assure proper operation under accident conditions. 10CFR50.49(e)(5) requires equipment to be replaced or refurbished at the end of its qualified life.

The licensee must establish a program to determine the maintenance, testing, and component replacement requirements from qualification documentation. The program must include incorporation of these requirements into the periodic maintenance and test program. The program must identify and control replacement of the entire device at the end of its qualified life, replacement of subcomponents such as seals, O-rings, and diaphragms that may age more rapidly than the overall device, and lubrication and testing specified as the basis of the qualification or required by the manufacturer to maintain qualification.

Maintenance and testing requirements for preservation of qualification must be incorporated into periodic maintenance and testing procedures for the devices. These periodic maintenance and test procedures must be performed as scheduled.

The licensee must establish procedural controls that assure restoration of qualified equipment to the as-qualified condition following scheduled and non-routine maintenance or testing. The licensee's procedural controls must require replacement materials and components to be in-kind replacements or that their adequacy for use in qualified equipment be established through appropriate evaluation or testing.

Modifications to qualified devices and systems containing qualified devices must be evaluated and controlled such that the modified devices and systems retain their qualified status. The licensee's program must require changes of materials, and interfaces to be evaluated with regard to the qualification of the devices. New electrical equipment important to safety used in modifications must be added to the list of equipment requiring qualification and the equipment must be qualified in accordance with the licensee's established procedures. The procedures for control of plant modifications must evaluate all modifications for their effect upon qualified equipment. For example, addition of fire barriers must be evaluated for their change to local environments such that a significant temperature change does not occur in the vicinity of qualified equipment.

The licensee's procedural controls must require the evaluation and appropriate incorporation into maintenance testing program of information, such as IE Information Notices concerning equipment failures and notifications by vendors of modifications to maintenance requirements or of recognized equipment deficiencies or problems, affecting the preservation of qualification of equipment.

The licensee's program for evaluating failures and significant out-of-calibration conditions should require evaluation of the deficiency with regard to the qualified life of the equipment. Failure of qualified equipment in service prior to the end of its qualified life may indicate that environmental or service conditions beyond those simulated in the qualification program are affecting the equipment or that the aging simulation during qualification testing was inadequate. If the failure mode could affect multiple applications of a device, the qualification of the device should be reevaluated.

The licensee's program must require procurement documents for new and replacement equipment to specify the qualification requirements of 10CFR50.49 for equipment requiring qualification. Section C.6 of Regulatory Guide 1.89, Revision 1, provides guidance for specifying qualification of replacement parts to requirements other than 10CFR50.49. The licensee's procurement program may allow procurement documents to have different levels of detail for different types of replacement components. For in-kind replacement of materials and parts, the specification of normal and accident environments need not be given and individual qualification testing of the materials and parts need not be required. However, the procurement documents for in-kind replacement must require materials and parts to be identical to those of the qualified equipment in which they will be used. Procurement documents for non-in-kind replacement materials, parts, and equipment must provide sufficient information to the vendor to allow qualification to be performed. (An alternative to this is licensee performance of qualification testing or analysis of the non-in-kind replacement components.)

10.0 PHYSICAL INSPECTION

The physical inspection of equipment requiring qualification will allow verification that qualification documentation is applicable to the installed equipment, that replacement and modification commitments have been implemented, and that the actual normal environments are in agreement with the specified normal environments. The physical inspection will also provide a general indication that the qualified status of equipment is being maintained and that all equipment requiring qualification has been included in the qualification program.

It is recognized that physical inspection will be limited by access conditions for the location of the equipment. When possible, the physical inspection should be scheduled during a major outage to allow access to harsh environment areas for which access is restricted during operation.

Prior to performance of the inspection, determine the following information for each of the selected devices:

- o the device description, manufacturer, and model number as documented
- o the safety function
- o location of equipment
- o the expected normal environment
- o shielding or environment modification requirements
- o mounting and orientation requirements
- o qualified interfaces.

This information may be obtained from the licensee's system component evaluation work sheets (SCEW sheets), the environment specification, the corrective action commitments list (for shielding and environmental modification), and qualification documentation for the equipment.

During the physical inspection, the following tasks should be performed:

a. Determine that the description, manufacturer, and model number match those of the documentation.

b. Determine that the location agrees with the documented location. Particular care should be taken with respect to compartment level for areas subject to submergence.

c. Note environments and check for indications of temperature and moisture in excess of the expected environment. For areas with recorded temperatures (such as the drywell), the recorded temperature may be checked.

d. The method of mounting and orientation of the device should be compared with that described in the documentation.

e. List any auxiliary devices mounted on or attached to the equipment that could affect operation.

f. Determine that the interfaces for the equipment are the same as those qualified (i.e., process connection, electrical connections, and housing seals are the same as those qualified).

g. Determine that all external compartment covers, gaskets, and seals are in place and that they appear to be in good condition. Record the general external condition of equipment.

h. Determine that any required shielding or additional HVAC equipment is in place and functional. In the case of shielding, determine that it is adequately supported and does not have a potentially adverse effect on the equipment, such as limiting cooling.

i. Note whether equipment may be affected by conductive heat transfer from the process connection.

j. Determine if non-safety-related equipment is in close proximity to the qualified device such that its failure could compromise the safety function of the qualified device. Record its existence for further verification.

Following the physical inspection, differences between the as-installed condition and the as-documented conditions should be addressed by the licensee. Such conditions as unexpected elevated temperatures and humidity conditions, loose covers, and improper mounting must be corrected. The licensee should be requested to review all other similar equipment. ?

11.0 QUALIFICATION ATTRIBUTES OF TYPICAL ELECTRICAL EQUIPMENT IN SAFETY-RELATED APPLICATIONS IN HARSH ENVIRONMENTS

This section lists environmental qualification concerns relating to specific types of equipment located in harsh environments. These concerns are based on knowledge of the equipment and reviews of existing qualification documentation. The concerns have been divided into three categories: documentation, physical inspection, and preservation of qualification.

11.1 Electronic Transmitters (Pressure, Flow, Temperature)

11.1.1 Documentation

a. Seals for electronics housings are generally critical for correct operation under accident conditions to prevent steam and contaminants from affecting electronic circuitry. A review of documentation should indicate whether these seals must be replaced each time the housing is opened for calibration or maintenance and whether periodic replacement of the seal is required to maintain transmitter integrity.

b. Transmitters with similar model numbers may have large variations in ranges and applications. Care must be taken in determining the ranges and applications for which the transmitters are qualified. Manufacturers provide charts for interpretation of model numbers. The qualification documentation should explicitly indicate the models that are qualified.

c. Transmitter electronics may be susceptible to radiation dose and dose rate effects. Transmitters must have been shown to be operational during accident radiation simulation. Variations in accuracy during irradiation must be addressed by the qualification documentation. Acceptability of such variations must be addressed for the application of the device.

d. The application of the transmitter may be limited by the process temperature. Qualification documentation or product literature should address these limits.

e. Mounting orientation may be limited to that of the qualification test or may require compensation of settings to account for variations in mounting unless the documentation justifies the applicability of the test mounting to other mounting methods.

11.1.2 Physical Inspection

a. The model number and range of the installed transmitter must be covered by the qualification documentation.

b. The process connection method used on the installed device should be the same as that described in the documentation file. Certain qualification tests indicated that particular types of process connections allowed leakage.

c. If non-seismic, non-hydrodynamic vibration from the process line or proximity to other equipment is identified on inspection, the qualification documentation should be reviewed to determine if such vibration was addressed.

d. Sealing of the transmitter housing is critical; therefore, all covers should be securely in place. All exposed seal edges should be in good condition and not be cracked or otherwise appear deteriorated.

e. If local indicators or other auxiliary devices are found to be connected to the transmitter, their qualification must be addressed in the documentation. Failure of such devices will generally prevent the transmitter from functioning.

f. The electrical connections and housing penetrations must be the same as those described in the documentation file. (Sealing of transmitter is generally critical to the function during accidents.)

g. If the transmitter is found to be below submergence level, the transmitter qualification must address submergence.

h. The mounting orientation and method must agree with the methods allowed by the qualification documentation.

i. The process temperature at the device must be within the limits prescribed by the manufacturer or the qualification of the device.

11.1.3 Preservation of Qualification

a. The maintenance and calibration intervals must agree with or be more conservative than those assumed in the qualification program.

b. If required, the maintenance and calibration procedures must address replacement of seals and gaskets upon removal of housing covers.

c. The calibration program should address evaluation of calibration drifts and zero shifts that are beyond the qualified limits. Such calibration drifts and zero shifts are, in reality, failures of the transmitters and should be evaluated to determine that the qualification program was adequate for the instrument or that conditions not considered during qualification have occurred during service.

11.2 Trip Switches

11.2.1 Documentation

a. During qualification, trip switch functional tests were sometimes performed by applying process test values equivalent to the setpoint, which does not demonstrate whether the switch would actuate at lower or higher pressures due to a setpoint or zero drift. Verify that during functional tests of the device, the actuation point was determined by gradually approaching the setpoint from a lower or higher simulated process condition as appropriate for the application (e.g., actuate on increasing pressure - test the device by approaching the setpoint from a lower pressure; actuate on decreasing pressure - test with process pressure approaching the setpoint from a higher pressure).

b. Trip switches, like transmitters, are subject to drift in their setpoints. Verify that the setpoint drift during qualification testing did not exceed the allowable tolerance defined in the acceptance criteria or that the setpoint drift recognized during qualification testing was evaluated for the plant-specific application.

c. Switches located below flood levels may be subject to electrical shorting as a result of in-leakage. For device locations susceptible to submergence, verify that testing was performed on the trip switch to verify its proper operation under submergence conditions.

11.2.2 Physical Inspection

a. During qualification testing, specific process and electrical connections are used. Verify that the connections used in the application are the same as those which were qualified or that justification for alternate connection systems have been provided.

11.2.3 Preservation of Qualification

a. Many gaskets and seals have limited qualified lifetimes. Identify any seals or gaskets with limited lifetimes in the qualification documentation, and verify that their periodic inspection/replacement is addressed in the maintenance program.

b. Most trip switches can maintain their setpoint accuracy for limited periods in use. Determine if the qualification documentation requires periodic adjustment or calibration of setpoints, and verify that these requirements are addressed in the maintenance program.

11.3 Radiation Monitors/Detectors

11.3.1 Documentation

a. Radiation monitors are normally qualified as a system which includes detectors, cables, electronics packages, and other accessories. Because the detectors provide very low-level signals, the qualification of the cable and connector system is critical to assure that the signal will be transmitted.

b. The electronics packages for the radiation monitors normally will not withstand a harsh environment (i.e., high temperature radiation or steam). Determine if the electronics must be located in a mild or relatively mild environment suitable for its qualification.

c. In qualifying radiation monitors, aging was sometimes considered for the entire device without addressing the materials of construction. Determine that the aging analyses identify the materials contained within the device and that the aging analysis is based on the most sensitive material.

d. Modifications were made to some radiation monitors during the testing to improve their performance without repeating steps of the testing already completed. Determine that evaluations of the effects of the modifications on the completed portions of the test program were performed.

e. Interconnecting cables used between detector assemblies and electronics packages should have been included in the qualification testing. Experience has shown that some of these cables require specific means of connection to ensure their integrity. Determine that the cable used during the testing is pre-qualified cable or that its qualification is completely covered by the test program and that any special connection methods are described in sufficient detail that they may be reproduced in the plant.

f. Radiation testing was not performed on some monitor systems. Determine that the effects of radiation were addressed for the equipment.

g. Determine that operation of the monitoring system was simulated during irradiation tests and that the system responded properly.

11.3.2 Physical Inspection

a. Manufacturers may have many different models under a generic equipment family. Determine that the devices installed in the plant are the qualified models.

b. As discussed in the documentation section, determine that the installed cable is qualified and that any special connections or seals used to qualify the equipment are used in the installation.

11.3.3 Preservation of Qualification

a. Many seals, gaskets, and electronic components have limited lifetimes in nuclear service. On the basis of the maintenance requirements in the qualification documentation, determine that the maintenance program addresses the periodic replacement/refurbishment of these components.

b. Since the qualification of the equipment may be dependent upon the cable and cable connection methods described in the qualification documentation, determine that the maintenance program establishes control over replacement/removal of interconnecting cabling.

11.4 Hydrogen Analyzers

11.4.1 Documentation

a. Qualification programs for some hydrogen analyzers did not include an analysis of materials used in the device. Determine that degradation as a result of aging was addressed for the materials used in the device.

b. Some analyzers were tested for limited accidents, and qualification to higher temperature and pressure profiles was not demonstrated. Determine that the accident profiles to which the device was qualified envelop the design conditions for the location of the equipment.

11.4.2 Physical Inspection

(No specific concerns)

11.4.3 Preservation of Qualification

a. Many of the components in the hydrogen analyzers have different qualified lifetimes and require replacement or refurbishment at different intervals. The maintenance program should be reviewed to determine that these intervals are addressed.

b. Some hydrogen analyzers require that the probes be wetted for proper operation. Determine that periodic maintenance or inspection programs address this requirement.

11.5 Accelerometers/Acoustic Monitors

Note: Accelerometers and acoustic monitors are normally made up of three primary devices: a sensor, interconnecting cable, and an electronics package.

11.5.1 Documentation

a. Many different models exist for sensors and electronics packages. It should be established that the models used in the plant are identical to the qualified model or that a similarity analysis was provided to establish qualification of the installed devices.

b. Electronics packages for some devices are not suitable for use in a harsh environment. It should be determined that the environmental parameters for the location of the equipment are enveloped by the qualification documentation.

c. Accelerometers and acoustic monitor sensors may require unique installations. The installation requirements identified in the qualification documentation should be reviewed for verification during the physical inspection.

11.5.2 Physical Inspection

a. The qualification documentation may require sealing of cable connections to prevent electrical shorting due to in-leakage during accident conditions. The connections should be inspected to determine that required sealing has been implemented.

b. Determine that the mounting method agrees with the qualified method.

11.5.3 Preservation of Qualification

a. Where special sealing or mounting requirements are specified in the qualification documentation, determine that the maintenance program controls removal and replacement of connections and mounting to ensure that the methods required by the qualification program are preserved.

11.6 Motorized Valve Actuators

11.6.1 Documentation

a. Due to the time period over which many motorized valve actuators were manufactured, shipped, and installed, the materials used in the construction of the actuators have changed, most notably the organic components. Verification of the similarity of the installed device to the qualified device is necessary.

b. The aging analyses for many of the actuators may not have addressed all organic materials. The aging analysis should address the motor winding insulation, motor lead wire insulation, lubricants, and the organic materials in switches and seals.

c. Failures have occurred during qualification testing of motorized valve actuators, most notably due to chemical attack on some motor insulations and radiation-induced failures of motor brake assemblies. Most qualification attempts for motor brake assemblies resulted in failure. If a brake is used in the plant, determine that acceptable qualification results are available.

11.6.2 Physical Inspection

a. Determine if the motorized valve actuator contains a motor brake assembly. If it does, verify that the qualification documentation includes the brake. Most mo . brakes have not been successfully qualified.

b. During qualification testing, water leakage into power and control terminal areas caused some valve actuator failures. Determine that the conduit connections for power to the motor and for control signals are sealed in accordance with the qualification documentation.

11.6.3 Preservation of Qualification

a. Although many motorized valve actuators have a qualified life claim of 40 years, the lubricants, seals, and gaskets require periodic replacement. Determine that the maintenance program makes provisions for addressing these items.

11.7 Solenoid Valves

11.7.1 Documentation

a. Continuous energization of a solenoid valve in service contributes significantly to the age-related degradation of elastomeric components as a result of temperature rises due to internal self-heating effects. Simply energizing the solenoid valve during a thermal aging simulation does not account for the increased degradation. Determine that the continuously energized solenoid valves have been identified and that the internal temperature rise due to self-heating effects has been included in Arrhenius calculations. For valves that were subjected to thermal aging while continuously energized, the internal temperature rises should be included in the calculation of the thermal aging temperature.

b. The materials used for seats and seals should be evaluated for their specific application. Viton has been shown to be susceptible to radiation damage when subjected to radiation doses exceeding approximately 20 Mrd and ethylene propylene terpolymer (EPDM) has been found to degrade as a result of air systems not being reasonably oil-free. Polyurethane has been shown to soften and adhere to other materials in the presence of water or oil at 140°F.

c. If the solenoid valve is required to perform a post-LOCA function, specified acceptance criteria for allowable seat leakage should be established. The seat leakage measured during qualification testing should be compared to these acceptance criteria to verify that the valves are adequately qualified for this service.

11.7.2 Physical Inspection

a. Solenoid valves contain many elastomeric components which are subject to thermal degradation. During the physical inspection, identify any solenoid valves mounted on or in close proximity to high-temperature process lines. For solenoid valves on or near high-temperature process lines, determine that the licensee has established the effect of the temperature rises (caused by conduction of heat from the process) on the qualified life of the components.

11.7.3 Preservation of Qualification

a. Most solenoid valves have limited qualified lifetimes and require periodic replacement of seats and seals or complete replacement of the device. Determine that the maintenance program requires periodic replacement of the seats and seals or of the entire valve, as required by the qualification program.

11.8 Limit Switches

11.8.1 Qualification Documentation

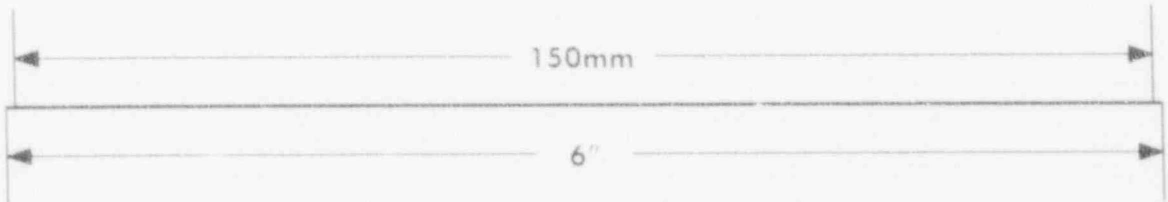
a. Some limit switches contain organic materials, such as nylon, which are susceptible to swelling when exposed to radiation. This swelling may affect contact position during irradiation, but may disappear within a few days of completion of irradiation. Verify that the limit switch was monitored and operated properly during the radiation simulation if materials that may swell have been used.

11.8.2 Physical Inspection

a. Most limit switches were tested with some type of conduit seal to prevent the entrance of moisture into the device. Determine that a qualified seal is used in the device installation.

2

IMAGE EVALUATION TEST TARGET (MT-3)



PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)

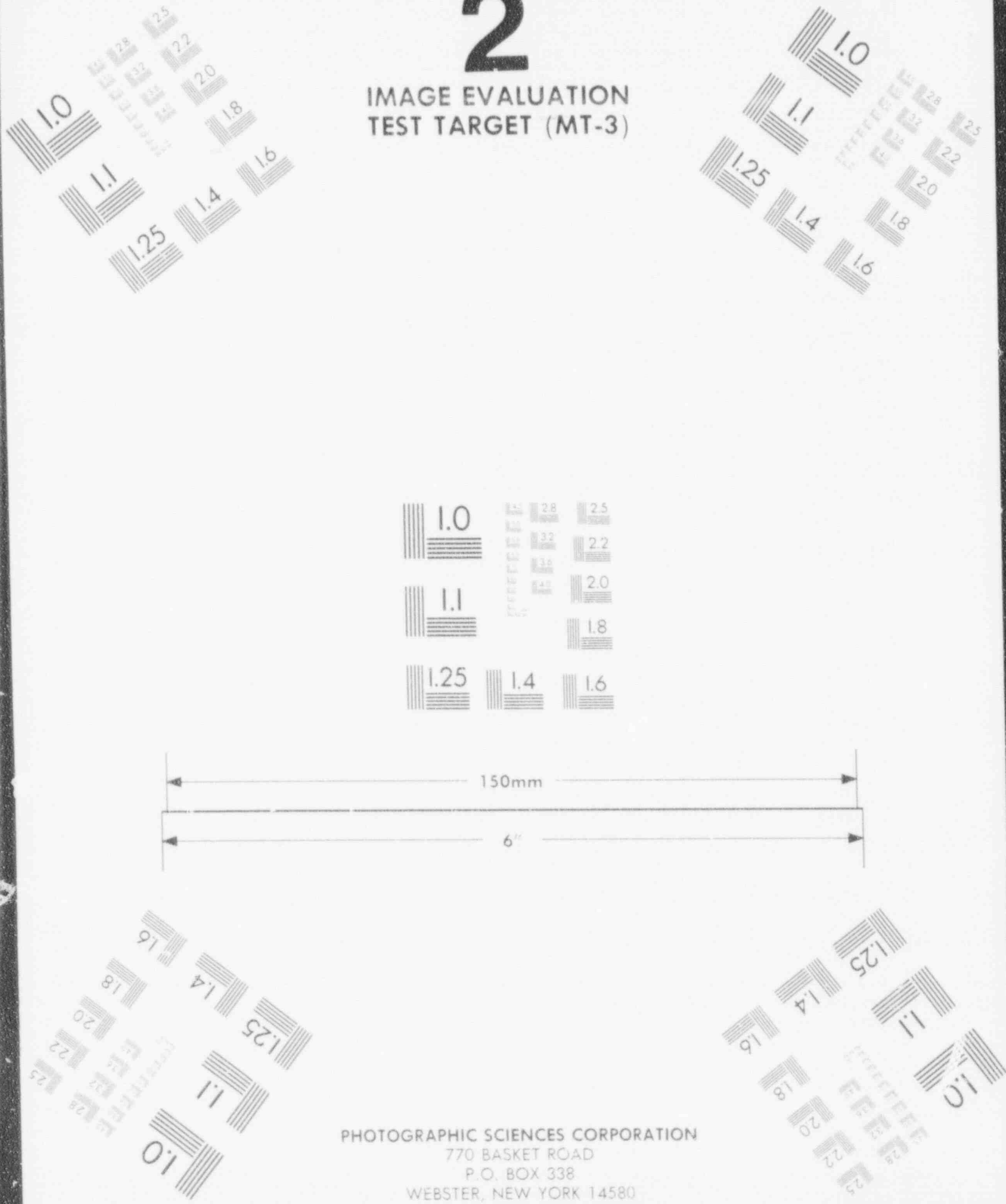
150mm

6"

PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)



PHOTOGRAPHIC SCIENCES CORPORATION
770 BASKET ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

2

IMAGE EVALUATION TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

150mm

6"

PHOTOGRAPHIC SCIENCES CORPORATION
770 BASK. , ROAD
P.O. BOX 338
WEBSTER, NEW YORK 14580
(716) 265-1600

b. Some manufacturers have qualified similar limit switches for different environments (i.e., inside containment or outside containment). During physical inspection, care must be taken to determine that the installed model is the model that is qualified for the environment associated with the location.

11.8.3 Preservation of Qualification

a. The seals and gaskets of most limit switches have been qualified for a limited lifetime. Determine that the maintenance program addresses their periodic replacement.

b. Some limit switches are qualified for only a 4- to 5-year period. Determine that replacement of such switches is included in the plant maintenance program.

c. Some limit switch manufacturers require periodic calibration of the device travel. Determine that the periodic calibration is addressed if required by the qualification documentation.

11.9 Electric Motors (Large, Continuous Duty)

11.9.1 Documentation

a. Bearing Lubrication - Lubrication of motor bearings is essential to continued motor operation. The qualification documentation should be reviewed to determine that the effects of radiation, aging, and contamination from accident environments and high temperature are addressed for lubricants. In addition, recommended maintenance intervals for testing or replacement of the lubricant should be identified.

b. The motor winding-to-lead wire splice and lead* wire should be addressed in the qualification documentation and should be qualified with the motor, or separate qualification documentation should be available.

c. Larger motors may be equipped with accessory equipment such as motor or bearing cooling systems or heaters. These accessories must be evaluated to determine if accessories are required for motor operation or if their failure would inhibit proper motor operation. If the accessories are required for operation, they should be

*The lead wire connects the winding to the motor terminals and is not to be confused with the external power feed cable for the motor.

environmentally qualified; if they are not required, an analysis should be provided showing that failure of the accessory will not cause motor failure.

d. Protective devices required to prevent motor damage should be qualified for their application and proven not to remove the motor from service inappropriately.

e. The junction boxes and method of termination of external feed cables for the motors should be identified for comparison with the installed device.

f. The orientation of the motor reported in the qualification documentation should be identified. (Large motors are generally designed for one orientation only, and the qualification documentation should be specifically for that orientation.)

g. The motor enclosure type used in qualification should be identified (e.g., sealed, open).

11.9.2 Physical Inspection

a. The motor nameplate data should be compared with the description in the qualification documentation. Pertinent information includes ratings frame size, insulation class, operating voltage and current, and enclosure type.

b. The motor should be physically inspected for accessories such as cooling jackets, heaters, or lubrication systems (e.g., pumps, valves). (Note: Disassembly of the motor to determine the presence of accessories is not recommended.) If these accessories are installed, it should be established that the support equipment is qualified or analyzed for the effect of its failure.

c. The motor housing should be inspected for loose or missing cover plates and for housing sealing methods other than those described in the qualification documentation.

11.9.3 Maintenance Documentation

a. Determine that maintenance procedures address periodic testing or replacement of lubricants as specified in the qualification documentation or supplemental vendor maintenance requirements.

b. Determine that maintenance procedures address replacement of bearings when required.

c. For sealed motors, determine that periodic inspection or replacement of any organic seals is performed as required by the qualification documentation.

d. For motors with open housings, determine that periodic cleaning of motor internals is performed.

11.10 Electrical Cable

11.10.1 Documentation

a. The most significant problem in establishing qualification of installed cable has been establishing similarity to the cable that was tested. To demonstrate similarity in accordance with IEEE Std 383-1974 [9], the following attributes should be compared:

1. Conductor - material identification, size, stranding, coating

2. Insulation - material identification, thickness, method of application (should include curing method)

3. Assembly (multiconductor cable only) - number and arrangement of conductors, fillers, binders

4. Shielding - tapes, extrusions, braids or others

5. Covering - jacket or metallic armor (or both), material identification, thickness, method of application (should include curing method)

6. Characteristics - voltage and temperature rating (instrumentation cable - capacitance, attenuation, characterististic impedence, microphonics, insulation resistance)

7. Identification - manufacturer's trade name or catalogue number

Note: As a minimum, a manufacturer's statement or certification that the qualification documentation applies to the installed cable should be available (e.g., a statement that the material used and construction methods are the same as those of the qualification specimens).

b. In cable qualification tests, functional capability was monitored during accident simulation. Verify that the monitored parameter was of interest for the cable application (e.g., impedence for shielded instrument cable).

c. The qualified life evaluation of power cable should include consideration of temperature rise from the currents passing through the cable.

11.10.2 Physical Inspection

a. Determine, on the basis of the attributes listed in Section B.10.1.a, that the installed cable is similar to the cable qualified. (Verification of manufacturing codes and numbers may be all that is possible.) Cable marking numbers should agree with qualification data. Obvious signs of mishandling or deterioration should be noted.

11.10.3 Preservation of Qualification

(No specific attributes)

11.11 Electrical Penetration Assemblies

11.11.1 Documentation

a. During qualification testing of electrical penetration assemblies, separate test specimens were used in many of the programs for different steps of the test sequence. Since this procedure is unacceptable, determine that a single specimen was exposed to all environmental influences required to demonstrate qualification.

b. Aging analyses for penetrations addressed only a limited number of materials. Determine that all non-metallic materials used in construction of the penetration were evaluated for the effects of age-related degradation.

c. Test documentation for penetrations has shown substantial reductions in insulation resistance during exposure to steam. For documentation where this is noted, determine that the licensee has evaluated the effects of the insulation resistance losses on instrumentation signals passing through the penetration.

11.11.2 Physical Inspection

a. Because of the many different types of modular and cellular penetrations in use, it should be verified that the qualified specimens are representative of the installed penetrations.

11.11.3 Preservation of Qualification

a. Because of the tendency of some epoxy and other organic materials to shrink with age, verify that the maintenance program addresses inspection and testing of penetrations to verify the adequacy of seal materials.

11.12 Splices, Terminations, and Connections

11.12.1 Documentation

a. During qualification testing, many terminations and connections were qualified while encased in external enclosures (e.g., junction boxes). Determine if the qualification documentation requires such enclosures to be installed.

11.12.2 Physical Inspection

a. Many different types and materials are in use for terminations, splices, and connections. Determine that the installed materials are those which were qualified.

b. Some manufacturers have placed limitations on the use of terminations, splices, and connections (e.g., two lug limit on a single terminal screw). Determine that any limitations established by the manufacturer are not exceeded in the installation.

c. Where qualification is predicated upon enclosure of the device, determine that the proper enclosure is provided.

11.12.3 Preservation of Qualification

a. Many manufacturers have provided explicit installation procedures for splices, terminations, and connectors. Determine that the maintenance program addresses use of these procedures for reinstallation after maintenance.

REFERENCES

1. "Guidelines for Evaluating Environmental Qualification of Class 1E Electrical Equipment in Operating Reactors," November 1979 (DOR Guidelines) issued as an Appendix to IE Bulletin 79-01B

2. NUREG-0588, Rev. 1, "Interim Staff Position on Environmental Qualification of Safety-Related Equipment," July 1981

3. Technical Evaluation Report (TER), "Review of Licensees' Resolution of Outstanding Issues from NRC Equipment Environmental Qualification Safety Evaluation Report." An individual TER for each operating power plant prepared by Franklin Research Center under NRC Contract 03-79-118

4. 10CFR50.49, "Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants," effective February 22, 1983

5. IEEE Std 323-1971, IEEE Trial-Use Standard: General Guide for Qualifying Class 1 Electric Equipment for Nuclear Power Generating Stations

6. Regulatory Guide 1.89, "Environmental Qualification of Certain Equipment Important to Safety for Nuclear Power Plants," Revision 1

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

8. EPRI, NP-1558, S. P. Carfagno and R. J. Gibson, "A Review of Equipment Aging Theory and Technology," Electric Power Research Institute, Palo Alto, CA, September 1980

9. IEEE Std 383-1974, Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations.

APPENDIX A

REMEDIAL ACTIONS FOR TER FINDINGS

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN
20th & RACE STREETS, PHILADELPHIA, PA 19103

This appendix first provides a list of eight generic corrective actions which may be taken by the licensee as corrective actions to resolve deficiencies in the TER. Although the eight corrective actions are not the only possible resolutions of the deficiencies noted during the review, they are the most common. Any proposed corrective action must be evaluated for its applicability in demonstrating qualification of the installed equipment.

Following the corrective actions is a brief description of the generic deficiency categories noted during the review of environmental qualification documentation submitted for 71 operating plants in response to IE Bulletin 79-01B. The reasons for citing a specific deficiency are included with each deficiency.

A.1.0 GENERIC CORRECTIVE ACTIONS

The corrective actions listed below can be applied almost universally to the deficiencies noted during the review.

a. Replacement of an unqualified device with a qualified device

b. Perform new qualification testing for existing equipment or acquire existing documentation

c. Perform similarity analysis to show that existing documentation applies to the installed device

d. Qualify by analysis (also extend qualification by analysis). In general, analysis should be used only for effects of one environmental parameter, since models for multiple effects generally do not exist

e. Modify service environment or provide shielding to allow use of existing documentation

f. Relocate equipment to mild environment

g. Exclude from scope of equipment requiring qualification (determination that equipment does not perform a safety function and its failure will not affect the performance of a safety function by another device)

h. Relocate equipment above flood level.

A.2.0 GENERIC DEFICIENCIES FROM TER

A.2.1 Documented Evidence of Qualification Inadequate*

a. Basis for Issuance of Deficiency:

1. Complete absence of documentation

2. Documentation did not address environmental qualification

3. Documentation consisted of a test summary only, or

4. Documentation consisted of a certificate of compliance (no other documentation provided).

b. Possible Corrective Actions (from D.1.0): A (typical)

a, b, f, g

A.2.2 Adequate Similarity Between Equipment and Test Specimen Not Established

a. Basis for Issuance of Deficiency:

1. System Component Evaluation Work Sheet (SCEW sheet) did not contain sufficient information to describe installed equipment adequately

2. SCEW sheet identified a model number different from the model identified in the qualification documentation

3. Test report contained only device tag numbers and no equipment model numbers, or

4. Equipment subjected to qualification testing had special modifications for testing.

b. Possible Corrective Actions (from D.1.0)

a, b, c, f, g

A.2.3 Aging Degradation Not Evaluated Adequately and Qualified Life or Replacement Schedule Not Established

a. Basis for Issuance of Deficiency:

---

*The TER deficiency descriptions were positive statements (e.g., "Document Evidence of Qualification Adequate"); here they are given in negative form for ease of interpretation of the deficiency.

1. Improper use of activation energies in aging calculations

2. Elimination of components subject to aging degradation from the aging evaluation without adequate justification

3. Extrapolation of manufacturer's recommended replacement intervals to forecast a longer qualified life without verifying the extrapolation with the manufacturer

4. Transposition and extrapolation of LOCA test environmental exposure to predict qualified life without adequate justification and analysis.

b. Possible Corrective Actions (from D.1.0)

a, b, c, d, e, f, g

A.2.4 Criteria Regarding Aging Simulation Not Satisfied

a. Basis for Issuance of Deficiency:

1. Aging simulation not performed prior to accident simulation (applies only to NUREG-0588, Category I qualification programs).

b. Possible Corrective Actions (from D.1.0)

a, b, d, f, g

A.2.5 Criteria Regarding Temperature/Pressure Exposure Not Satisfied

a. Basis for Issuance of Deficiency:

1. Peak Temperature Inadequate

(a) Peak temperature during qualification testing did not envelop plant-specific conditions.

2. Peak Pressure Inadequate

(a) Peak pressure during qualification testing did not envelop plant-specific conditions

(b) Accident testing was performed at ambient pressure.

3. Duration Inadequate

(a) Testing was performed for 1 or 2 hours at elevated pressure and temperature and used as evidence of qualification for longer periods

(b) Accident testing was performed for 30 days with a specified plant accident duration of up to one year.

4. Required Profile Enveloped Inadequately

(a) Failure of qualification results to envelop the specified accident conditions.

5. Steam Exposure Inadequate

(a) Accident testing was performed in an air oven at elevated temperature with no steam exposure.

b. Possible Corrective Actions (from D.1.0)

a, b, f, g

A.2.6 Criteria Regarding Spray Not Satisfied

a. Basis for Issuance of Deficiency:

1. Chemical/demineralized water spray was not used during accident simulation

2. Material analyses were performed to qualify equipment for chemical spray without considering the increase in reactivity of the spray solution with increases in temperature or the effects of chemical plateout.

b. Possible Corrective Actions (from D.1.0)

a, b, d, e, f, g

A.2.7 Criteria Regarding Submergence Not Satisfied

a. Basis for Issuance of Deficiency:

1. Equipment was identified as subject to submergence, but no testing was performed, or

2. Equipment was identified as completing protective actions prior to submergence, but no failure analysis was provided to demonstrate that the equipment's failure when submerged would not affect other class IE equipment.

b. Possible Corrective Actions (from D.1.0)

a, b, h or performance of a failure effects analysis (for case 2 above only)

A.2.8 Criteria Regarding Radiation Not Satisfied

a. Basis for Issuance of Deficiency:

1. No test or analysis for radiation withstand capability was provided,

2. Equipment failed or exhibited aberrant behavior when exposed to radiation, or

3. Material analysis did not address the critical properties of the material for its application in the equipment.

b. Possible Corrective Actions (from D.1.0)

a, b, e, f, g

A.2.9 Criteria Regarding Test Sequence Not Satisfied

a. Basis for Issuance of Deficiency:

1. Equipment containing materials subject to age-related degradation was not aged,

2. Equipment containing materials subject to radiation damage was not irradiated, or

3. Testing was performed on different test specimens with no one specimen subjected to entire test sequence.

b. Possible Corrective Actions (from D.1.0)

a, b, f, g

A.2.10 Inadequate Resolution of Test Specimen Failures or Severe Anomalies

a. Basis for Issuance of Deficiency:

1. Equipment failed during initial phases of accident testing,

2. Equipment failed at longer term point of accident testing (e.g., failure at 15 days) with inadequate evaluation of the failure and accident simulation stresses

3. Significant instrument accuracy or setpoint changes were noted, or

4. Test equipment anomalies caused exposure transients with equipment failures resulting without adequate evaluation or analysis of event.

b. Possible Corrective Actions (from D.1.0)

a, b, f, g

Note: In cases where equipment failure occurred that was not attributable to inappropriate testing; replacement, relocation, or exclusion from scope should be used rather than retesting.

A.2.11 Criteria Regarding Instrument Accuracy Not Satisfied

a. Basis for Issuance of Deficiency:

1. Instrumentation was tested, but no data on accuracy or setpoint and zero drift were provided, or

2. Data on accuracy and drift were provided with no evaluation of adequacy for the specific applications.

b. Possible Corrective Actions (from D.1.0)

a, b, f, g