Condition Based Qualification

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- Project Lead IEEE 323/60780 Harmonization
- Member IEEE 1682, 1202, 848, 1205, 98, etc
- Member IEEE/IEC Condition Monitoring
- IAEA CRP Condition Monitoring Member
- IEC SC 45A Expert
- Contributor DOE/NRC Cables 60 Yr & Beyond
- Member EPRI Cable Users Group

Overview

- Many Plants World Wide Are Aging
- PVC & Other Less Thermal & Radiation Resistant Insulation & Jacket Used WW
- Plants Want To Know When To Replace
- Expect Condition Based Qualification To Help

Plant Life Extension

- US Plants Extending From 40 to 60 Years
  - 73% Done + 18% Applied – Little Upgrades
- New Plants Starting at 60 Yrs: Extend to 80 Yrs
- France Rolling 10 Yr Reviews
  - 2009 ASN Approved EDF's Safety Case for 40 Yr Operation of 900 MWe Units, Based on Generic Assessment of 34 Reactors
- Russia Extending Most Reactors From Original 30 Yr for 15 Yr (25 Yr for Newer VVER-1000)
  - With Significant Upgrades

DOE/NRC Report

- Report Cables & Concrete Limiting Factors to Plant Life Extension Beyond 60 Yr
- Based on a Group of Experts
- Report Complete on Cables 60-80 Yrs & Beyond But Not Published Should Be Out Shortly
- Let’s Look At Information On Manufacturer's and Cable Used in US Plants

US Nuclear Cable Manufacturers

Table 2.1. Top Ten manufacturers and insulations used in nuclear plants

Rank	Manufacturer	Database Entries	Percentage of total
1	Rockbestos/Cerro	363	23
2	Okonite	359	23
3	Boston Insulated Wire	150	9
4	Anaconda Wire and Cable	128	8
5	Kerite Company	109	7
6	Brand-Rex	98	6
7	Samuel Moore	77	5
8	General Electric	69	4
9	Raychem	46	3
10	Continental Wire & Cable Corporation	37	2
	Subtotal of top ten manufacturers/suppliers	1436	90
	Total	1590	100

Source: EPRI TR-103841 (1994) [15]

US Nuclear Suppliers

- 34 Manufacturers Listed
  - Of Those 10 Manufacturers 90% of Total
- Top 3 - 55% of Total
- BIW, Anaconda, GE, Raychem, and Continental No Longer Supply Nuclear Cables
- Marmon Companies Plus Raychem = 38%
- 33% Discontinued = 71%

Manufacturer's & Insulation

Table 2.2. A sort of the 34 manufacturers' insulations for US NPPs

Rank	Manufacturer	Insulation	Plants
1	Rockbestos	Firewall III XLPE	61
2	Anaconda Wire and Cable	EPR	35
3	Brand-Rex	XLPE	30
4	Okonite	EPR	26
5	Kerite Company	HTK	25
6	Rockbestos	Coax XLPE	24
7	Raychem	XLPE	23
8	Samuel Moore	EPR	19
9	BIW	Bostrad 7E EPR	19
10	Kerite®	Flame retardant EPR	13

Manufacturer's & Insulation

- Sorting Shows XLPE and EPR 72% of Total
- Top 4 Materials (XLPE, EPR, Silicone and Kerite) Over 80% of Total
- Jackets Generally Used Were Neoprene, PVC, CSPE and CPE
- PVC and Neoprene No Longer Used
- Today 90%+ LV RSCC Class 1E
  - Most FRXLPE Insulation & CSPE Jacket
  - MV EPR Insulation & CSPE/TSCPE Jacket

General International Materials

- MV
  - PVC or XLPE Insulation
  - PVC Jacket
- LV
  - PVC, LSZH, EPR Insulation
  - PVC, LSZH, Neoprene, CSPE Jacket

Condition Based Qualification

- Qualification Based On Measurement Of One Or More Condition Indicators Of Equipment, Its Components, Or Materials For Which An Acceptance Criterion Can Be Correlated To The Equipment's Ability To Function As Specified During An Applicable Design Basis Event

Condition Indicator

- Measurable Physical Property of Equipment, Its Components, or Materials That Changes Monotonically With Time And Can Be Correlated With Its Safety Function Performance Under Design Basis Event Conditions
- Condition Indicators Shall Be Leading Indicators Of Adverse Change In Condition Directly Related To Equipment's Ability To Function And Directly Related To Degree Of Ageing Performed In Program

Use of Condition Based Qualification

- To Use Condition Based Qualification, Age Conditioning Is Performed Incrementally
- Condition Indicators Are Measured At Increments To Establish Data For Comparison With Observations Of Same Indicators During Service
- Qualified Condition is Value of Condition Indicator(s) At The Conclusion Of Age Conditioning, Prior To Testing To Accident Conditions (Only Normal Radiation)

Cautions

- Since Measurements For Condition Indicators May Be Taken At One Temperature Additional Data May Be Required To Correlated With Time And Temperature (Arrhenius)
- Measured Changes Shall Allow Distinguishing The Degree Of Ageing And Shall Be Consistent Enough To Establish A Qualified Condition
- The Method Used And Performance Of Condition Monitoring Shall Provide For High Accuracy And Reproducibility

Condition Monitoring

- Condition Monitoring For Equipment Qualification Purposes Monitors One Or More Condition Indicators To Determine Whether Equipment Remains In A Qualified Condition
- The Equipment Remains Qualified Until It Reaches A Point Prior To The End Condition That Takes Into Account Margin

Extension Of Qualified Life

- As Equipment Approaches The End Of Its Theoretical Qualified Life, Periodic Condition Monitoring May Be Implemented To Determine If Actual Ageing Is Occurring At A Slower Rate, And If Further Qualified Service Is Possible Based On The Condition Monitoring Results
- Or Equipment May Age Faster & Will Have To Be Replace

Points To Consider

- Still Need To Do Aging (Arrhenius To IEEE 98, 99, 101, etc) – Will Review Later
- Still Need To Do DBE Test
- Additional Testing To Test Condition Indicator & Correlate To Time – Generally By Arrhenius

Generic End Point

- Many Have Not Determined End Points
- Want To Have A Generic End Point
- Example 50% Absolute Elongation For Insulation
- Have To Do DBE Test & Validate Passes, So Generic End Point Not For Cables That Have To Pass DBE – Review Issues For Non-DBE

Generic End Point Issues

- Should Not Be Used When Another Material is Limiting Factor
  - Such as Bonded Jackets: Crack Propagation Issue
- Where Jacket Can Be Limit
  - Such as Insulating Jackets on Coaxial Cables
  - Shielded Cables (EMC Issues, Ground Loops, etc)
- Where Jacket is Seal in Splicing or Terminating
- When Jacketed is Moisture Barrier for Insulation (ex if Singles are Not Wet Rated)

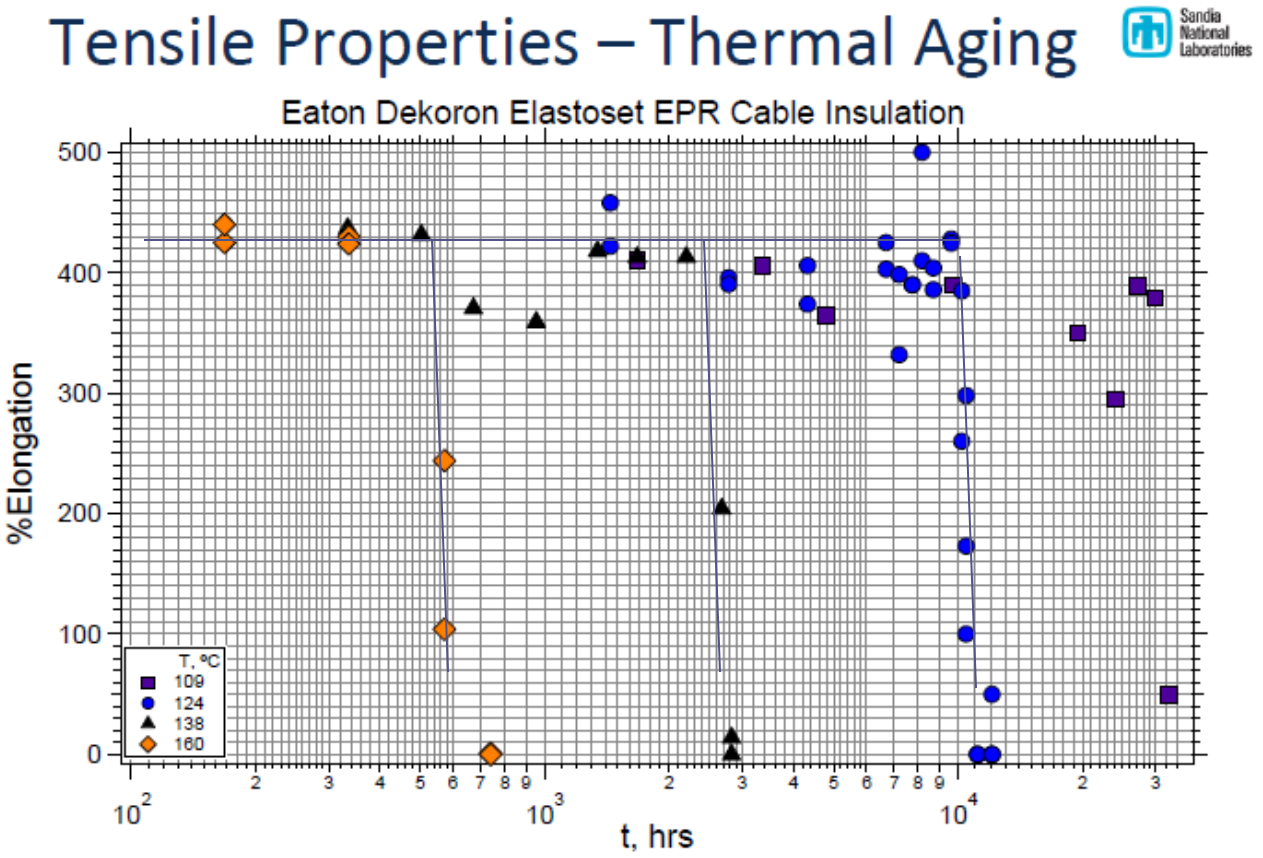
Generic End Point Issues

- When Insulation Not Flame Retardant Enough & Jacket Needed to Maintain Flame Retardance
- When Jacket Used to Prevent Tracking (or Other Barrier Function) Such as With Kapton
- When Jacket Cracking or Falling Off Can Cause Sump Issues and Jacket is Limiting Case
- When Jacket is Beta Shield and Higher Elongation May be Required To Survive Accident for This Case

Generic End Point Issues

- Degradation of Materials That Soften Polymer (Such as Hydrolysis or De-polymerization) Should Not Use This: Butyl, Urethane, etc
- When Insulation is Very Soft, With Low Tear Strength and Other Mechanical Considerations May be Required (Silicone Rubber)
- Where Voltage Or Other Parameter is The Limit Instead Of Elongation (Some EPR, PVC, etc)
- Where Material Has An Avalanche Effect

Avalanche Effect



SAND2005-7331 K. T. Gillen, R. A. Assink, and R. Bernstein

PVC

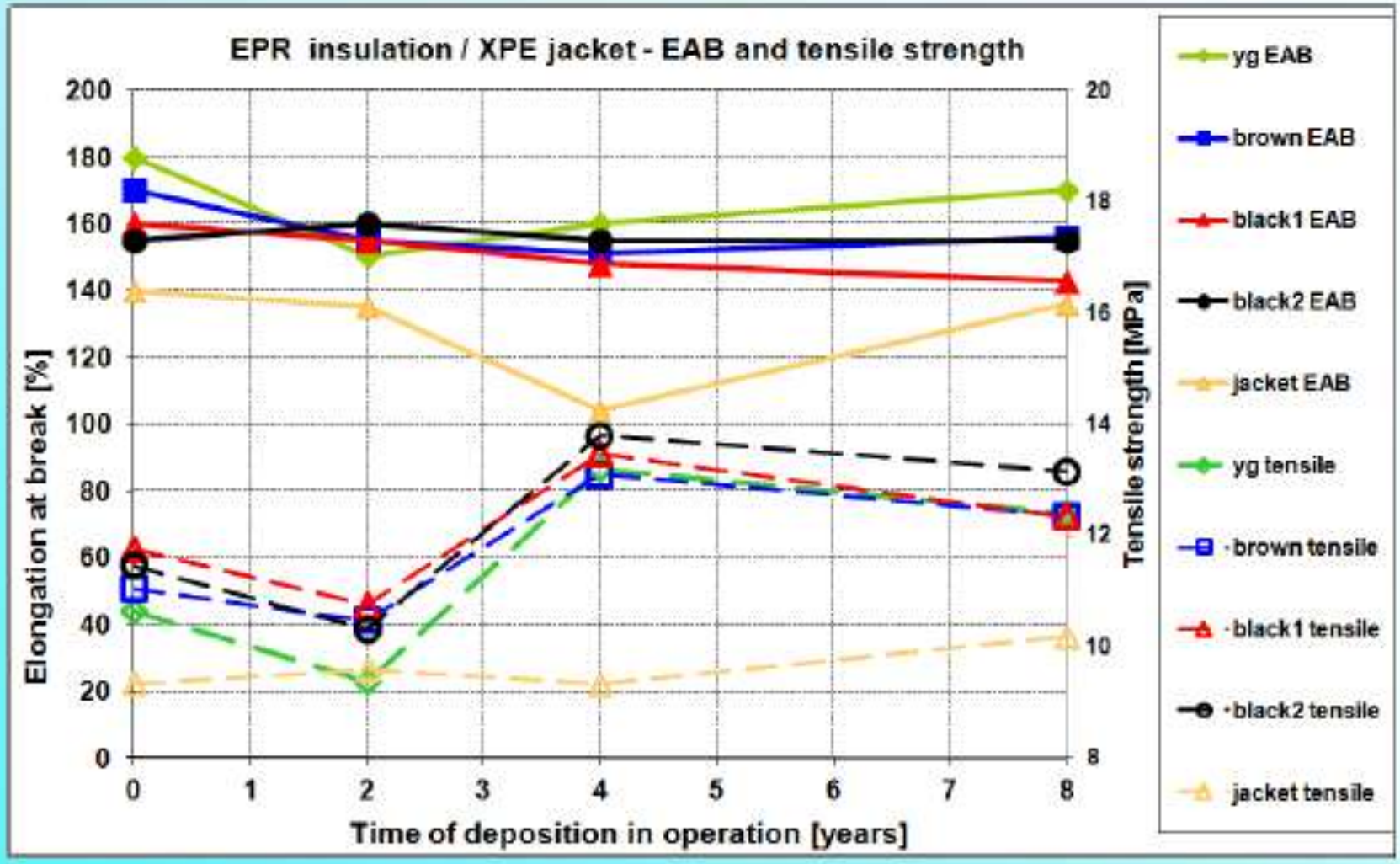
- PVC generates hydrogen chloride (HCl) when exposed to radiation which forms ionic salts which may be mobile from plasticizer migration causing material to become conductive when subsequently exposed to steam
- Seen At Low Radiation Levels
- A Generic End Point Cannot Be Used
- Should Not Be Used In Nuclear Plants

Practical Considerations

- If Use Elongation At Break As End Point
  - What is Variability Of Initial Elongation At Break
    - Example 150%: Maybe 125% to 175%
      - Need To Have Initial Value For Every Cable?
  - How Does This Effect Condition Indicator?
    - If Use Jacket As Condition Indicator, Now May Have Safety Function That Did Not Before: How Control
- What If Get A Low Point? Just Shut Down Reactor & Replace All Cables?

Bohunice 3&4 Cable deposit – Results example

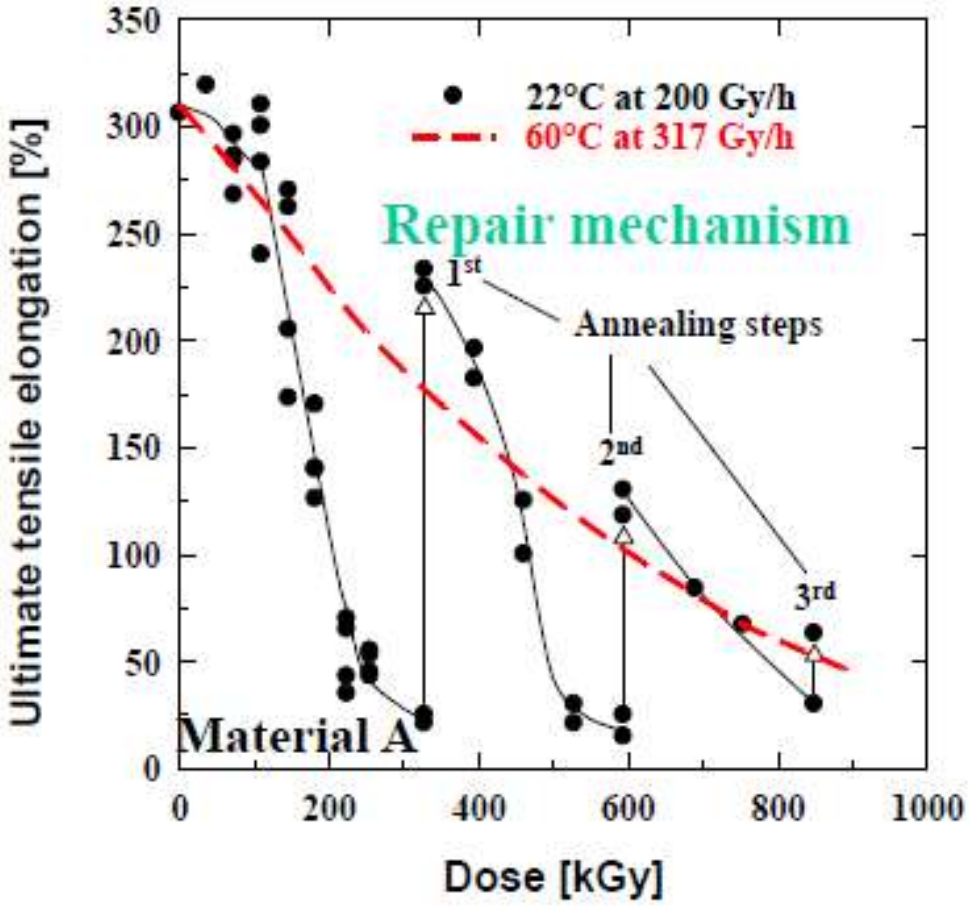
Cable 1-CHKE-V/LOCA 4Bx1,5 – EPR insulation, XPE jacket



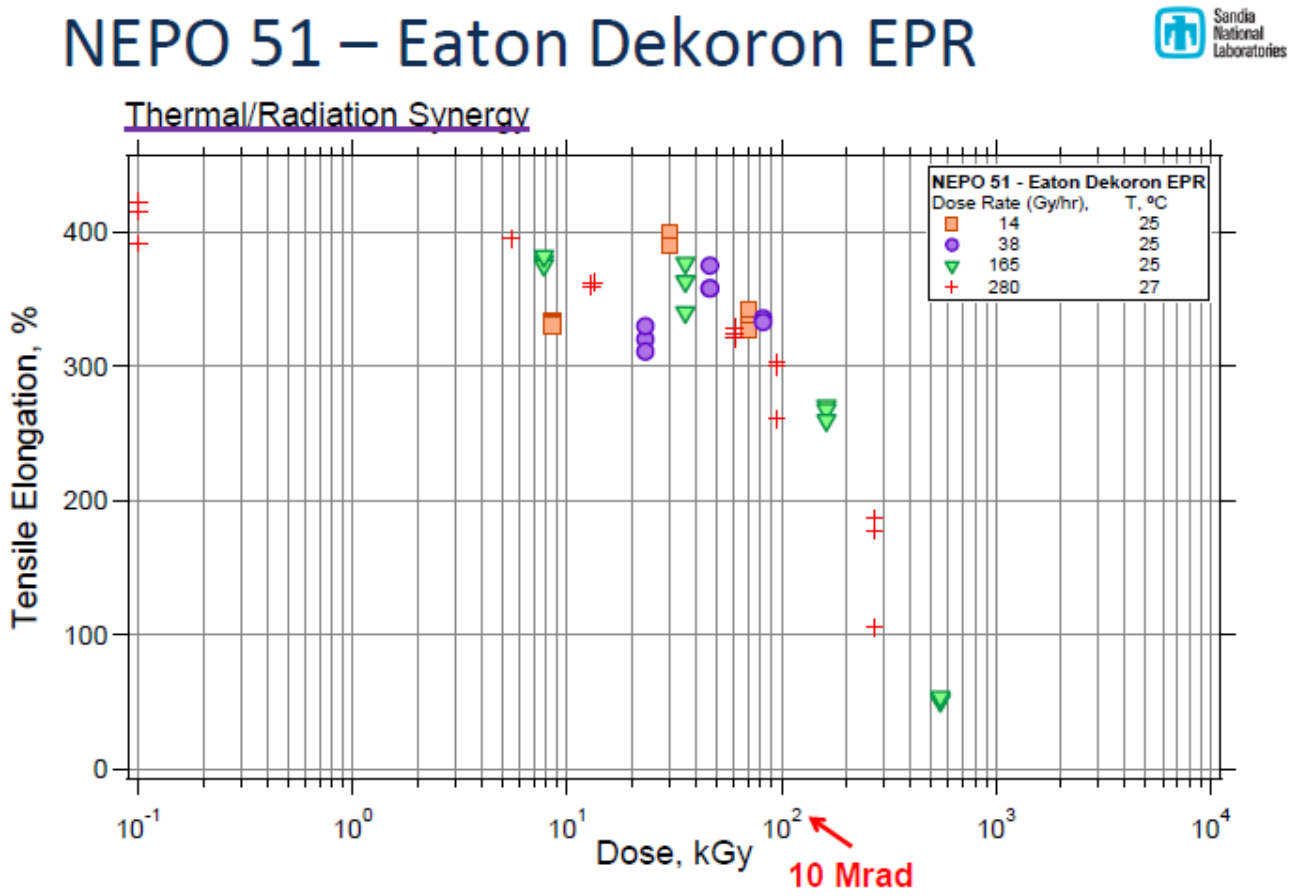
If Use Initial Qualification

- Aging May Have Been Low (7 Days: 121°C, 136°C, 158°C): May Be No Change In Elongation
- Only Change Would Be Radiation
- Would This Be Valid If Aging Is Thermal Dominated (Probable In Most Areas)?
  - How Handle Radiation When Do Condition Indicator?
- How Do You Get At Hottest Areas (Center Of Tray, In Conduit, Etc) To Test? Internal Heating?
- Crystallization, Dose Rate, Oxygen Diffusion, Synergies, Etc All Still Apply In Getting End Point (Does It Matter How Get There)

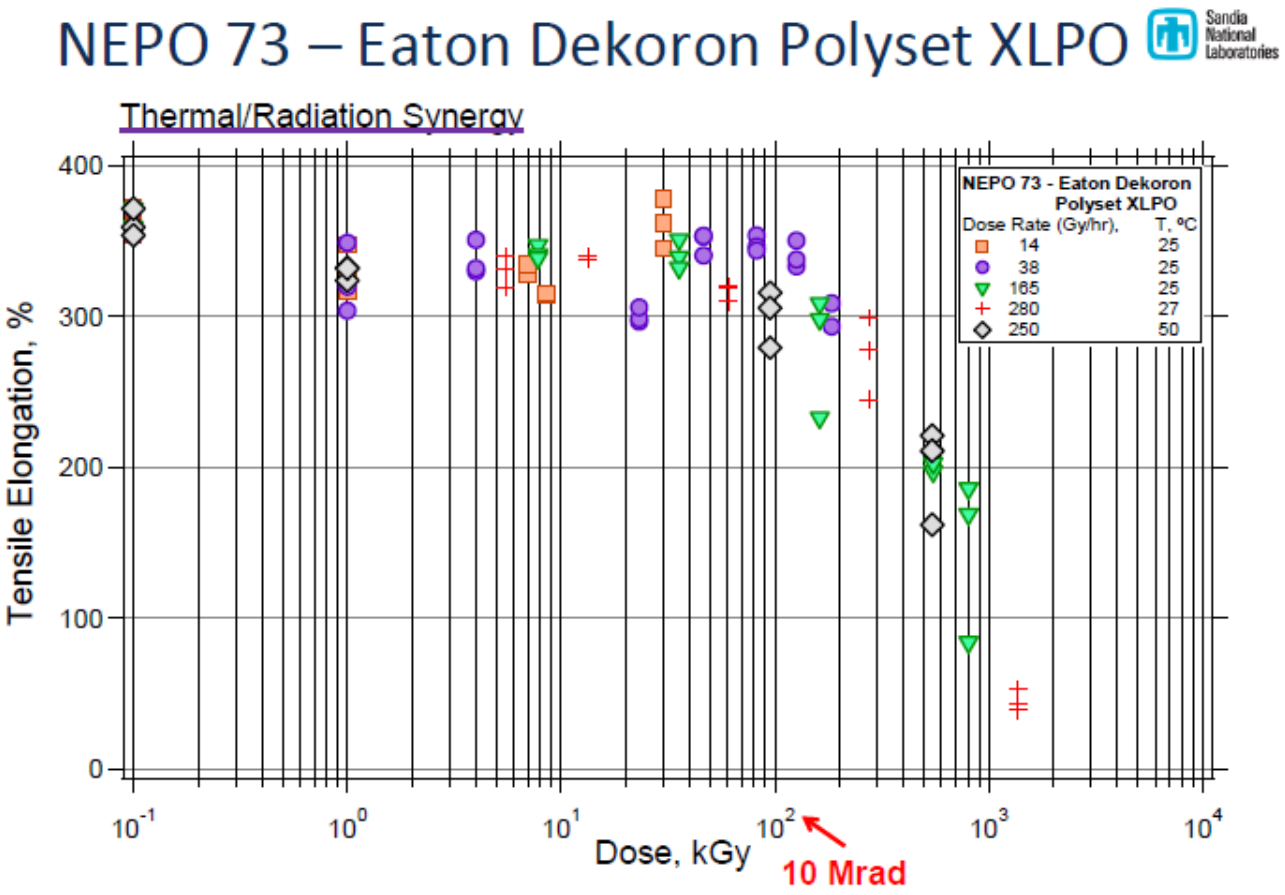
Crystallization



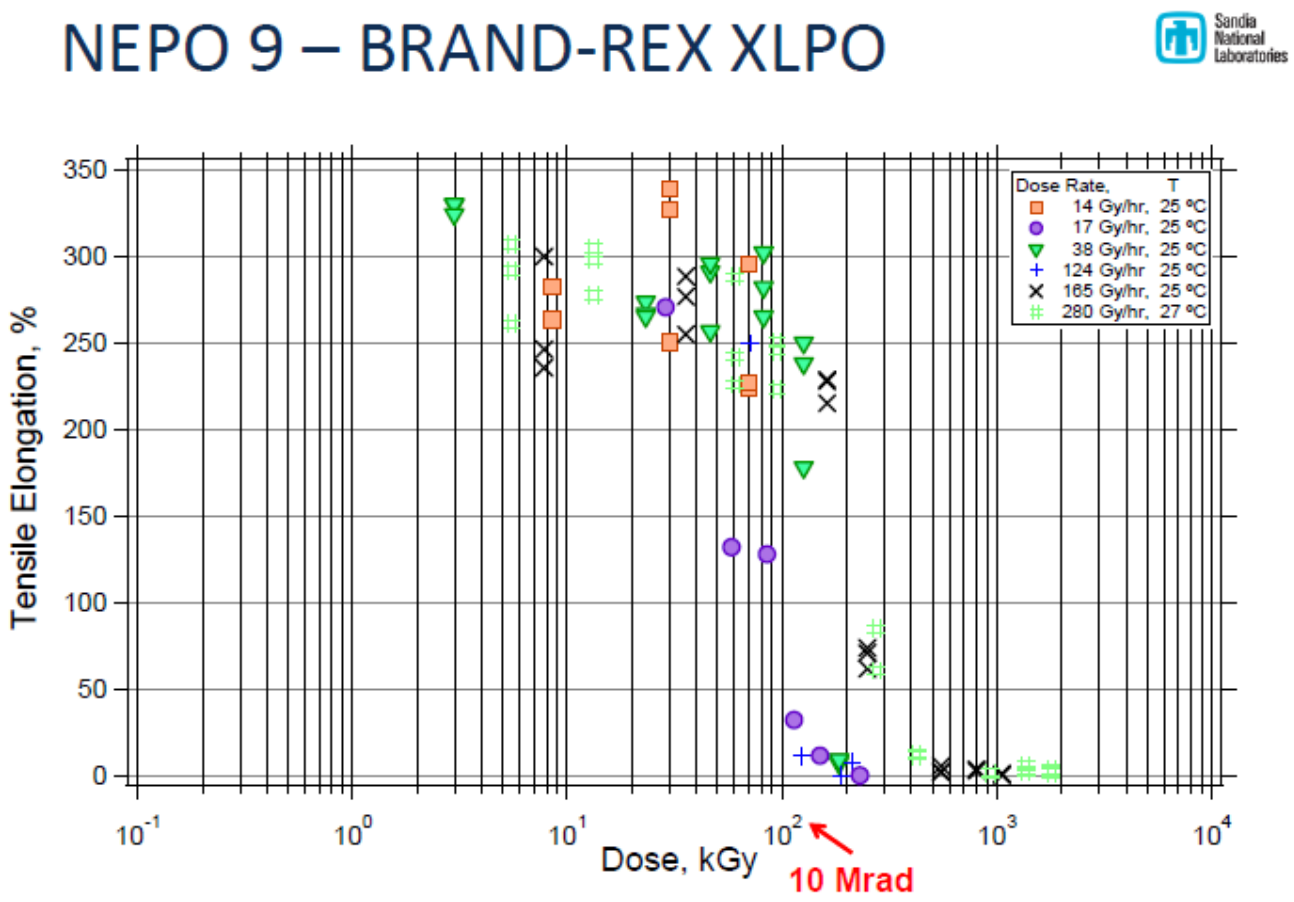
Radiation EPR



Radiation XLPO



Radiation XLPO



IEEE/IEC 62582

- Nuclear Power Plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods
  - Part 1: General
  - Part 2: Indenter Modulus
  - Part 3: Elongation at Break
  - Part 4: Oxidation Induction Techniques

General

- Condition monitoring should only be applied if there is a known relationship between the ageing degradation of the component monitored and the degradation of the equipment's safety function
  - Jacket Colour Change – May Indicate Some Thermal or Radiation Damage: May Not Translate To Insulation Function
  - Generally Still Use Arrhenius Relationship When Translate in Time

General

- Qualification To Determine Relationship
  - Diffusion Limited Rate Effects
  - Preponderance Of Cross Linking vs Chain Scission
    - Simultaneous Aging, Dose Rate, etc
- If Significantly Effects Polymer, Need To Determine How To Get in Qualified Condition To Pass DBE & What Represents For Time
  - Just Because Have 50% Elongation May Matter How Get There (Cross Linking or Chain Scission)

General

- Qualified Condition
  - Generally 50 Mrads or Less Normal Dose
  - Aging To End of Life
- Many Polymers 50% Retention Or More
  - Example One Company Used 80% Retention of Elongation, But Shifted Line
    - Result Sample Was At 104% Elongation
- Many Examples Where Aging 7 Days at 121C or 136C. Many Insulations Aged 7 Days at 158C Still Close To 100% Retention of Elongation

General

- Many Test Have Done 100 to 200 Mrads Of Radiation, Then DBE Performed
- Cannot Use This As Qualified Condition
  - Accident Dose Has To Be Done Separately
- Margin
  - Also Need To Ensure Margin

Indenter Modulus

- EPRI Has Many Reports On This
- Area Must Be Accessible
- Generally Most Severe Areas Not Accessible
- Good For Hot Spots To Look At Jacket Damage
- Hard To Use For Energized Power Cables
- Best For Rubber Jackets – Leading Indicator
- Use of Plastic Type LSZH or XLPO Jackets Will Limit This Option

Indenter Modulus

- Indenter Modulus Is Correlated To Elongation At Break Via Arrhenius Method
- Insulation May Not Be Accessible
  - Jacket Indenter Modulus Correlated To Jacket Elongation At Break Via Arrhenius
  - Then Have To Look At If Leading Indicator
  - Also Need To Look At Dose Rate Effects, Oxygen Diffusion, Variability, etc
- Best As A Tool To Look At Hot Spot Damage

110C Aging

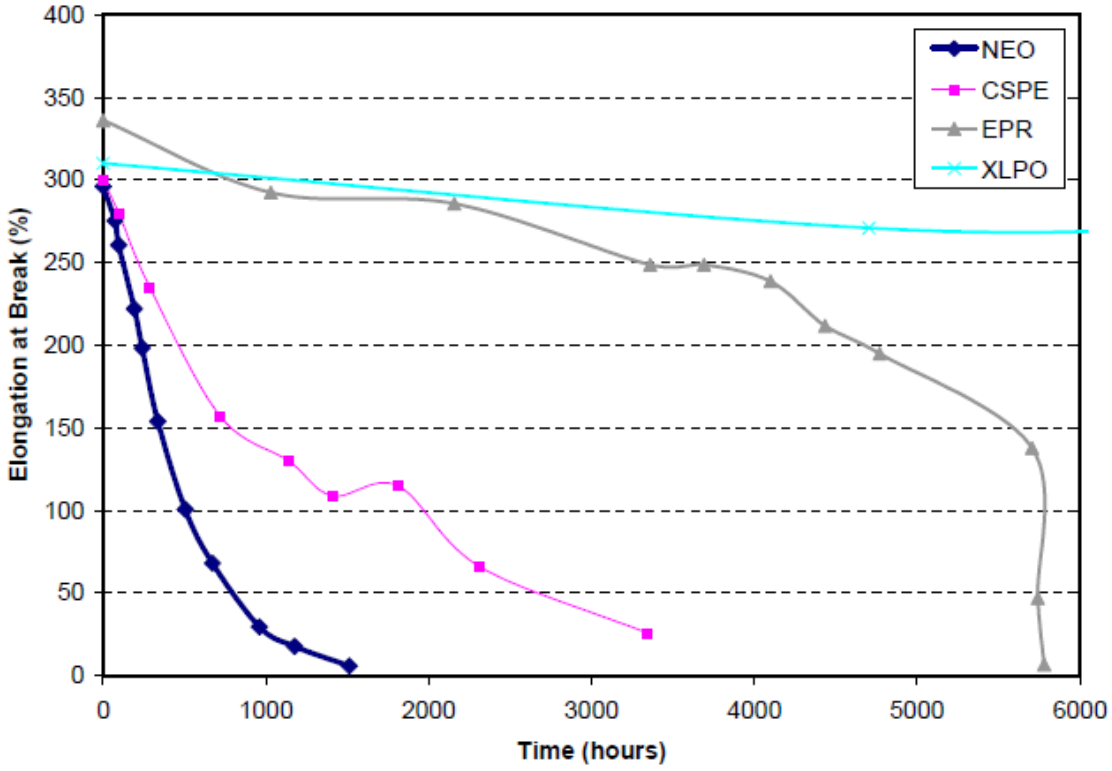


Figure 5-2
Nature of Aging of Cable Materials, 110°C Aging: Neoprene, CSPE, and EPR Subset

Not All Material Equal

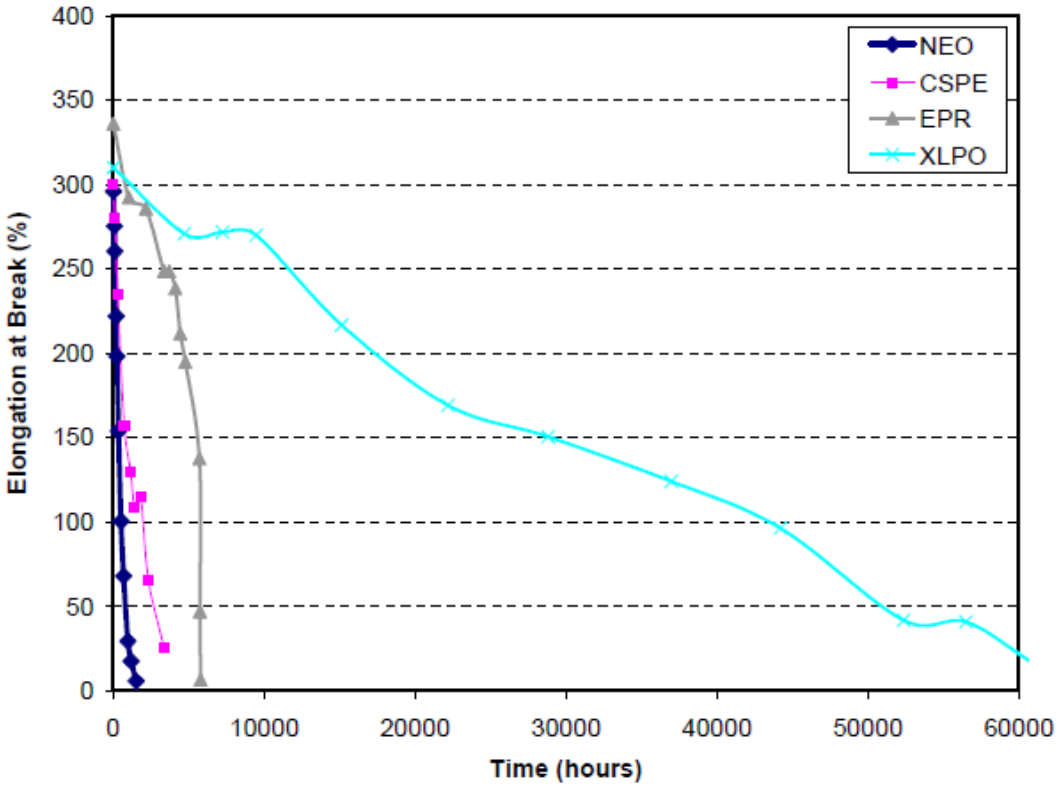


Figure 5-1
Nature of Aging of Cable Materials, 110°C Aging

Oxidation Induction Techniques

- Condition Monitoring Method
  - Not Finding Good Correlation
  - Have Same Issues As With Indenter
    - Only Accessible – Plus Destructive So Need Sample
    - Have To Correlate (Not Seeing This Easily)
    - How Effect By Rate, Variability, etc
    - In The End Still Test Elongation At Break To Correlate

OIT At Various Temperatures

- Higher Temperature, Higher Activation Energy and Life Projection

- Will Look at EB on Same Issue

Material	OIT Temp (°C)	Activation Energy (eV)	60 Year Temp (°C)
XLPE 1	220, 230, 240	1.8	108
XLPE 1	190, 200, 210	1.36	83
XLPE 2	220, 230, 240	1.7	103
XLPE 2	190, 200, 210	1.5	90

Elongation at Break

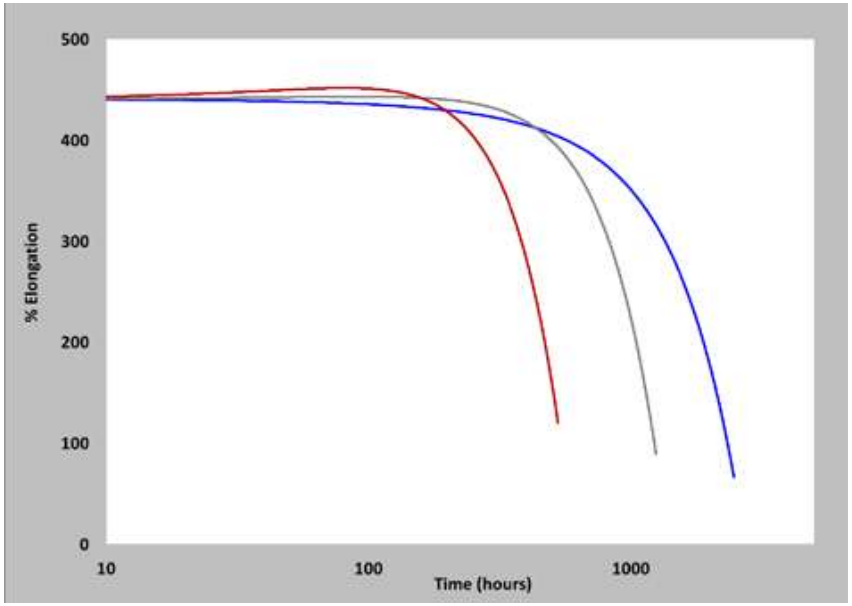
- Used For Initial Qualification
- Has Been Used For Deposits
  - Takes Very Long Time To Get Usable Data
  - Thin Samples With Oxygen All Around
    - Conservative vs Jacket & Thermal Drop
- Correlations For Thermal Alone
  - IEEE 98 Only For Thermal Aging
  - Comparing OIT and EB
  - Looking At Available Industry Data

OIT Vs EB

- OIT Shows Higher AE
- Not Always Longer Life
- Value As Screening Tool In Formulating – If Big Change in Same Material
- Quality Control Tool
- Still Doing More Work

Material	Method	Act Energy (eV)	60 Year Temp (°C)
XLCPE	EB	1.08	70
XLCPE	OIT	1.26	64
XLLSZH	EB	1.24	71
XLLSZH	OIT	1.61	69
FREPR	EB	0.97	68
FREPR	OIT	1.34	80
EPR	EB	1.2	80
EPR	OIT	1.33	72

EB High Temperature Aging

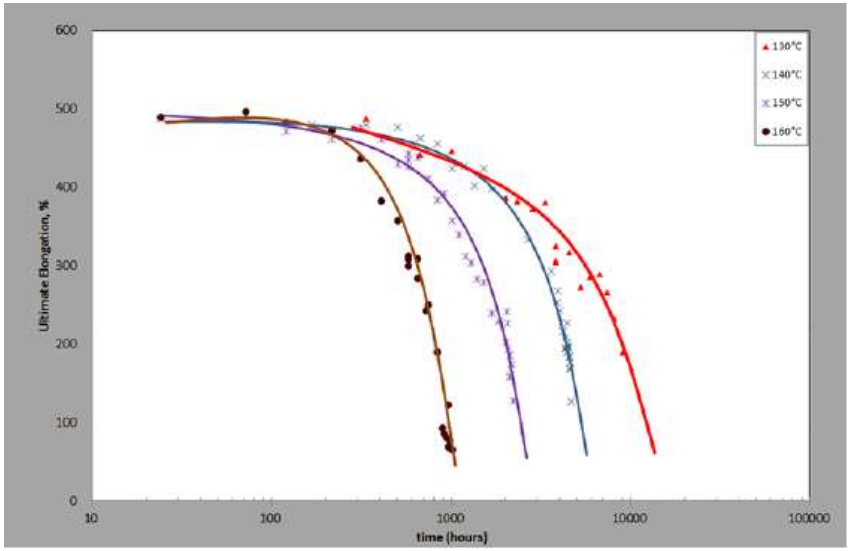


- Using 170C, 160C, and 150C
- Get 60 Years At 95C, AE ≈ 1.3
- Does Not Meet IEEE 5000 Hour Point Requirements
- Extrapolated Data

Example Chart

Comments

Lower Temperature Aging



- Using 160C, 150C, 140C & 130C
- Get 60 Years at 88C
- Use 150C, 140C & 130C
- Get 60 Years at 83C, AE ≈ 1.04
- Indicates 2nd Order Reaction
- Note Data Extrapolated

Example Chart

Comments

Discussion

- Lower Temperatures And Longer Times Seem To Give More Repeatable & More Realistic Data in OIT and EB
  - Have To Put In Time To Get Good Data
- Look Out For Second Order Reactions In EB
- Elongation At Break Still The Best Method
- Some Plants Still Have Deposits
- Some Plants To Be Decommissioned & Opportunity To Look At EB

Operating Experience

- Have Over 40 Years Operating Experience on Some Cables
  - In US Bad Actors Purged In Class 1E
  - Some Materials Not Used in US Reactors
    - FEP/PFA/MFA Type: Very Low Radiation Tolerance
    - PVC: Many Issues Including Plasticizer Migration
    - Neoprene: Not Great Aging, Some Better Than Others
  - No Generic Aging Issue In US
  - Mostly XLPE, EPR and SR Insulation
  - CSPE Jacket or Braid For SR

Operating Experience

- For Wet Installations For MV
  - No Definitive Qualification Test
  - Dissipation Factor May Be Leading Indicator
  - Operating Experience Best Indicator
    - Some Water Treeing Issues
    - Others Issues With Shield Layer Interface
    - General Insulation Thermal Aging Not Seen
    - Conductor Shield Layer May Be Issue Thermally

Recommendations

- Deposits & Elongation At Break Most Practicable, But Maybe 20+ Years For Useful Information & Must Significantly Age Cable Before LOCA
- History Best Indictor Of What Working
  - Have 40+ Years
    - See How Much Thermal Aging & Radiation Degradation
    - History Best Indicator of Wet Aging of MV Cables
- Walk Down Best To See Hot Spots
- Review DOR Aging & Material Lessons Learned

Recommendations

- Initial Qualification Very Important
  - Watch How Arrhenius Done
  - Make Sure Test 1/C Without Jacket
    - Can Shorten Thermal, Not Steam/Water
  - Watch Oxygen Diffusion With Jacketed Cable
- Design & Installation Important
  - Design/Materials Must Be Flexible Enough, But Tough Enough To Be Installed Without Damage
  - If Rely on Jacket Cannot Damage – How Know?

QUESTIONS