Optical Fiber Cable Environmental Qualification

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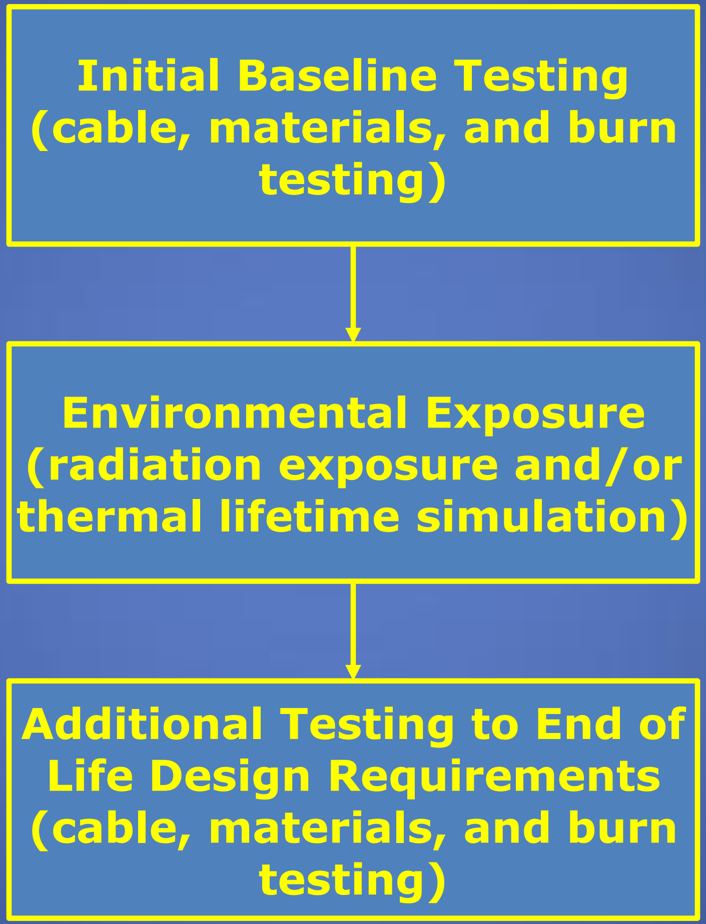
Basic Steps in Cable EQ

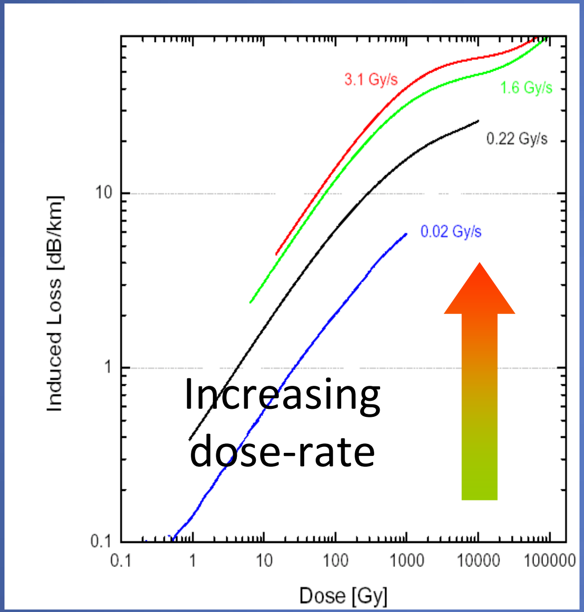


Optical Fiber in Radiation Environments

- Standard optical fibers may be highly sensitive to radiation even at low doses
- Radiation effects on fiber performance must be carefully characterized before deployment into high radiation environments
- Different fibers may be required for different applications

Rad Hard Fibers - Basic Concepts

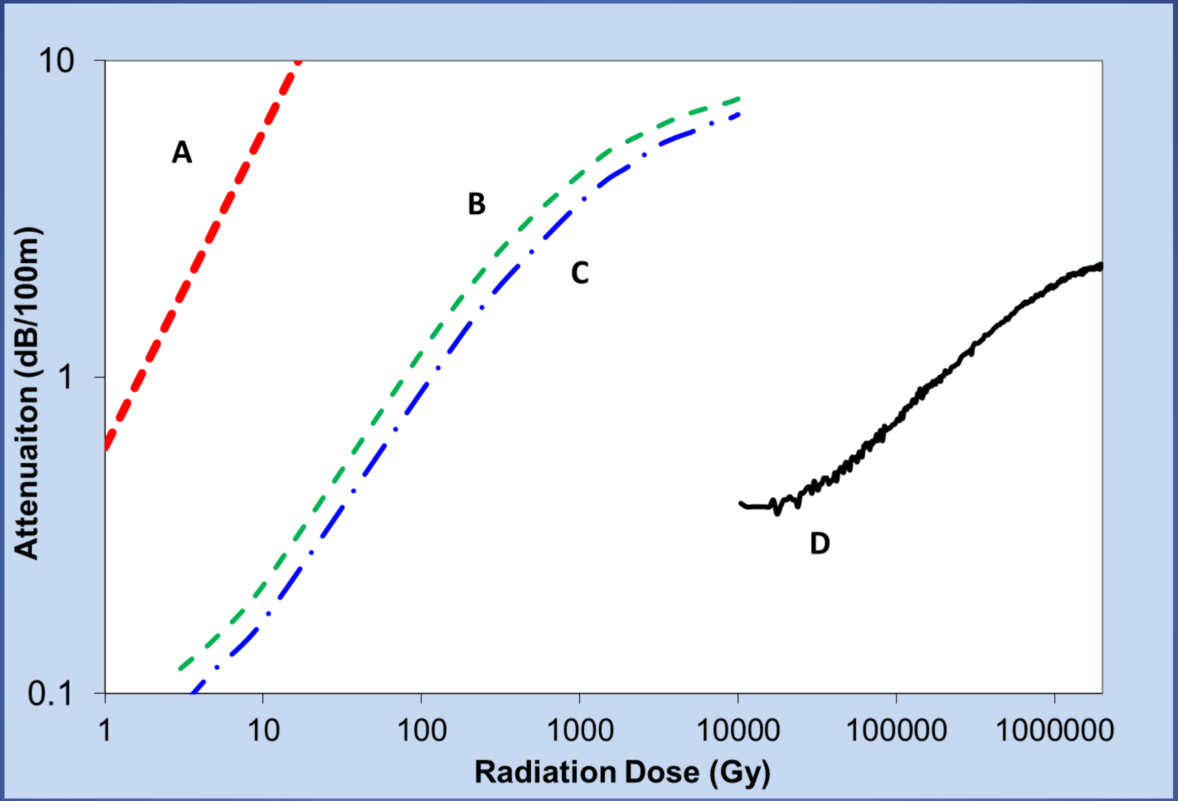
RIA is a function of the total dose and dose-rate



Measurements performed by J. Kuhnhenn, Fraunhofer Institute, 2005

- RIA generally increases with increasing dose
- RIA generally increases with increasing dose-rate
- RIA generally decreases (anneals) after the radiation is removed

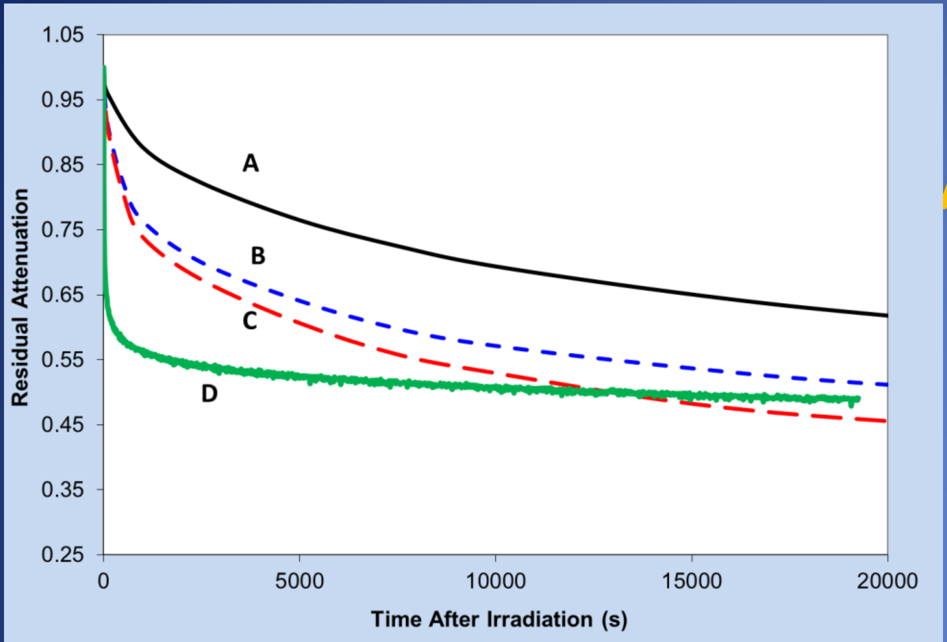
RIA Comparison of MM Fibers

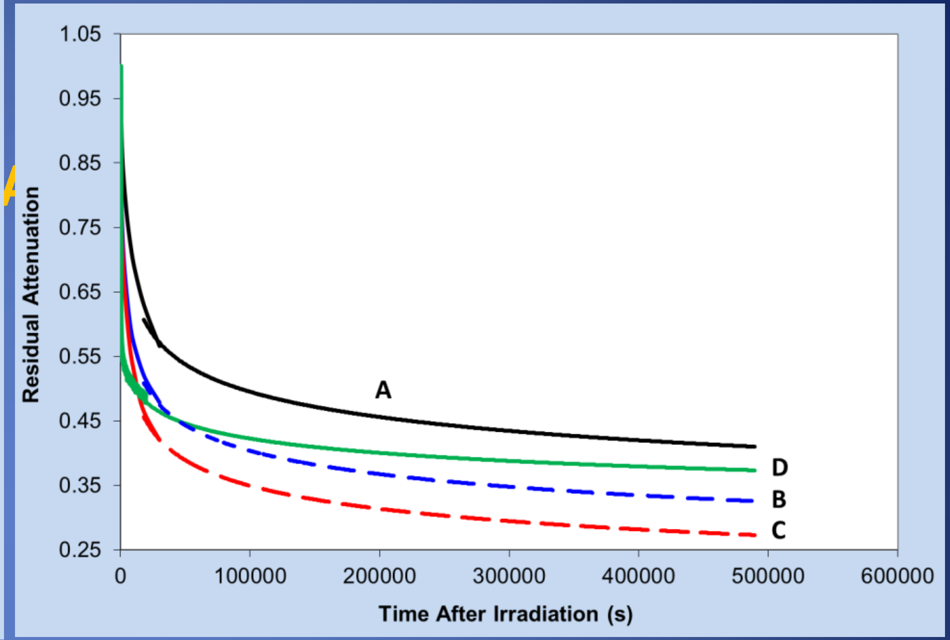


A. P-Doped 50 Micron Multimode Fiber
B. 50 Micron Ge doped PCVD – Rad Hard
C. 62.5 Micron Ge doped PCVD – Rad Hard
D. 50 Micron F doped PCVD – Super Rad Hard

Fibers containing phosphorous should not be used in high radiation environments.

Annealing

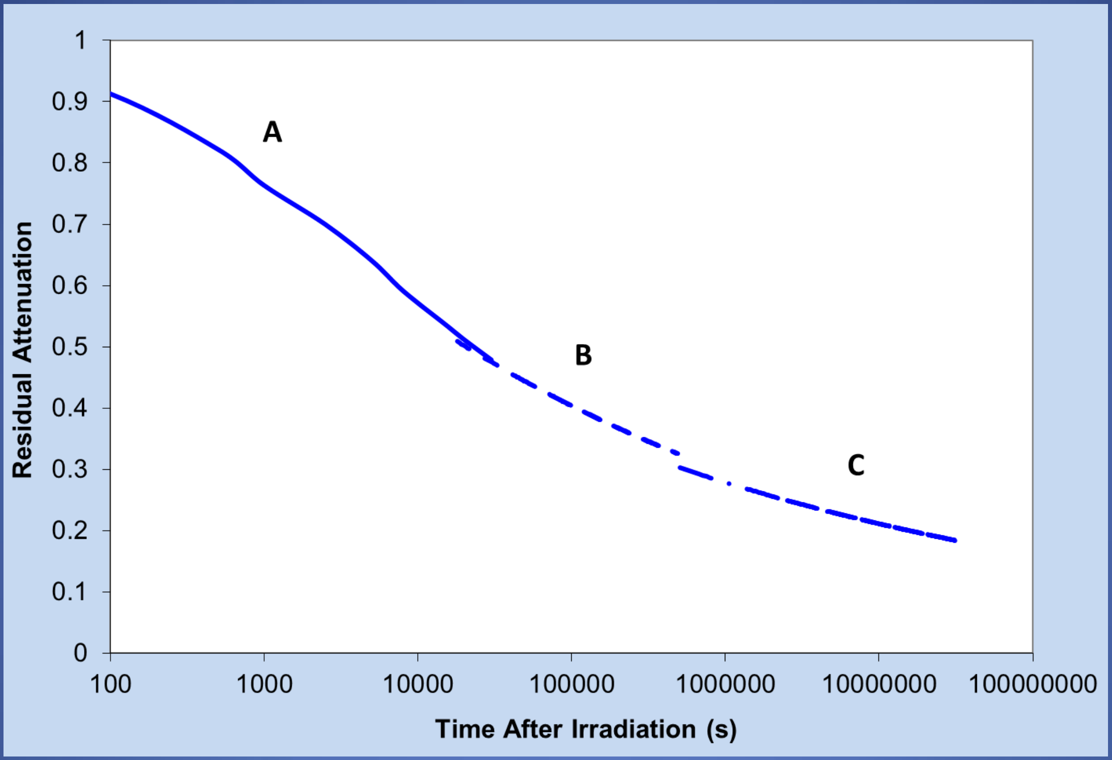




A. Ge doped PCVD SMF (Rad Hard)	C. Ge doped PCVD 50 Micron MMF (Rad Hard).
B. Ge doped PCVD 62.5 Micron MMF (Rad Hard)	D. F doped PCVD SMF (Super Rad Hard)

RIA recovery may be reduced or totally absent for Rad Hard fibers!

RIA Annealing Cabled vs. Bare Fiber



Long Term Annealing on PCVD Multimode Radiation Resistant Fiber Measured at 1310nm

A Fiber Test 1 B Cable Test 2 C Cable Test 1

Behavior is identical for both bare fibers and cabled fibers

Prysmian Optical Fibers
Super RadHard & RadHard @ 200 MR

Fiber Type	RIA	Wavelength
RadHard SM	22 dB/100m	1310nm
Super RadHard SM	1 dB/100m	1310nm
Super RadHard 50 µm	2.2 dB/100m 4.7dB/100m	1310nm 850nm

Comparative typical instantaneous attenuation values for optical fibers at a dose of 2.0MGy (200Mrad) and a dose rate of 1.25Gy/s.

The performance benefit of SRH fibers increases with increasing dose and time.

Prysmian Optical Fiber Strength Before and After Irradiation >200 MR

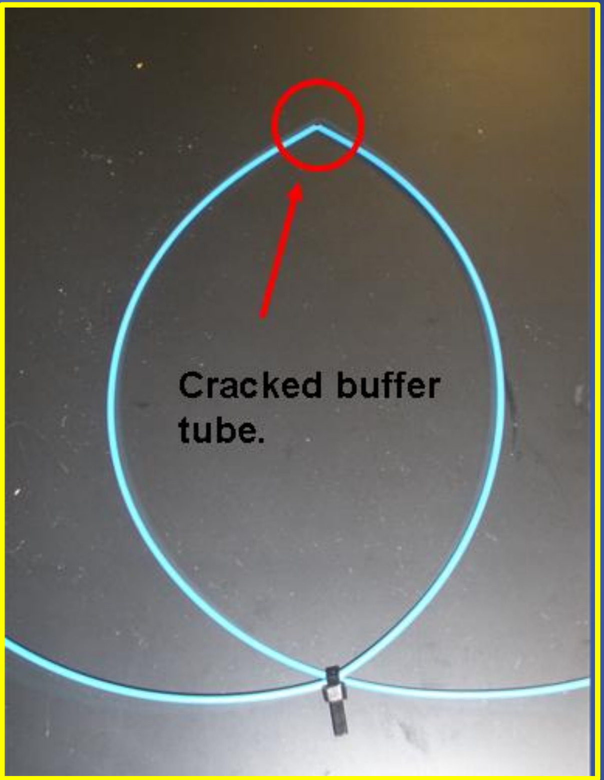
Radiation Conditioning	Fiber strength (kPSI)	Dynamic fatigue (n)
None	810	22
2.35MGy	895	30.9

Conclusion:

Optical fiber strength is not reduced even after exposure to extremely high radiation doses (> 200 Mrad)

Cable Material Arrhenius Testing
End of Life Criteria

OR

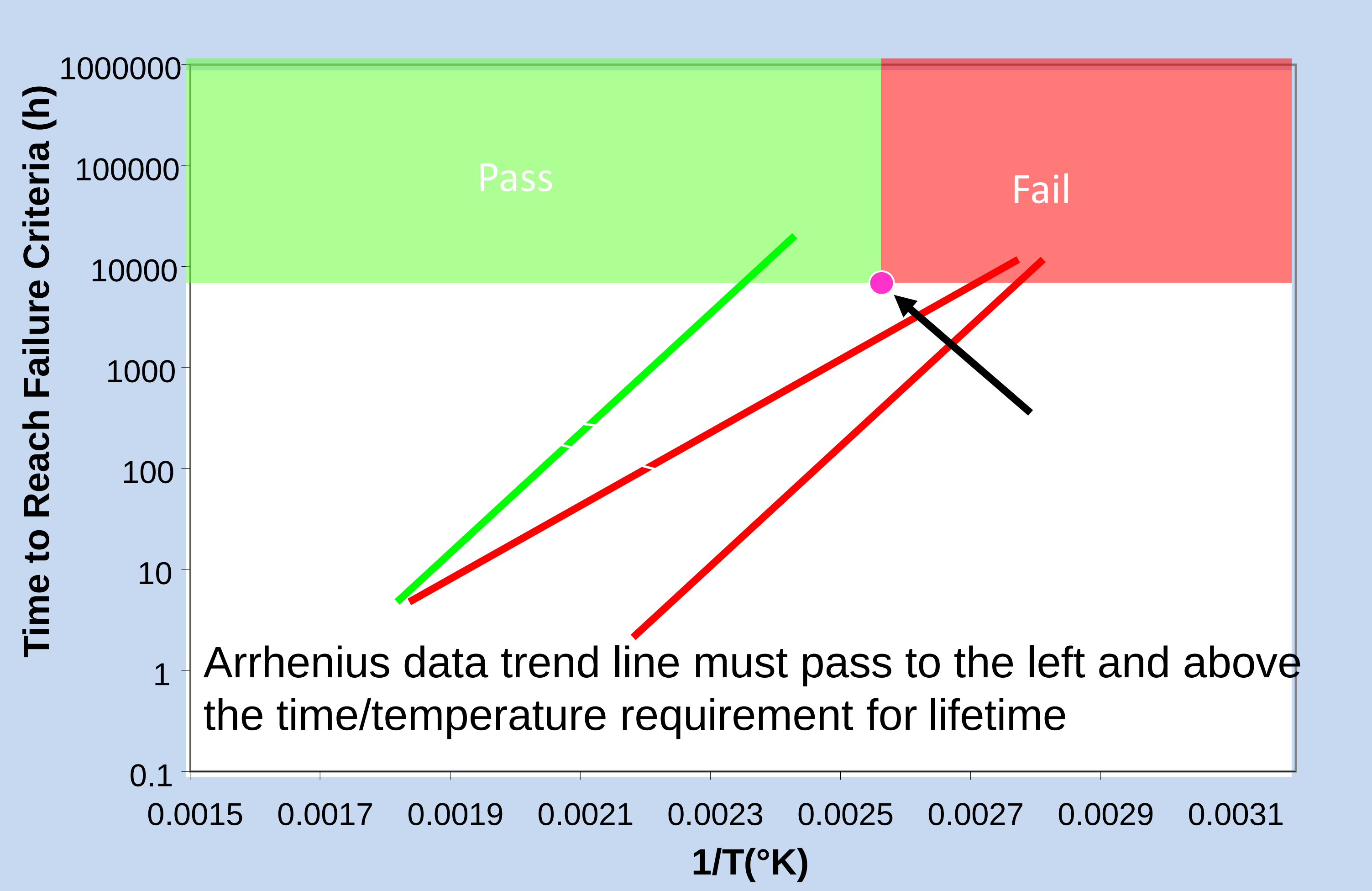


Change in Elongation

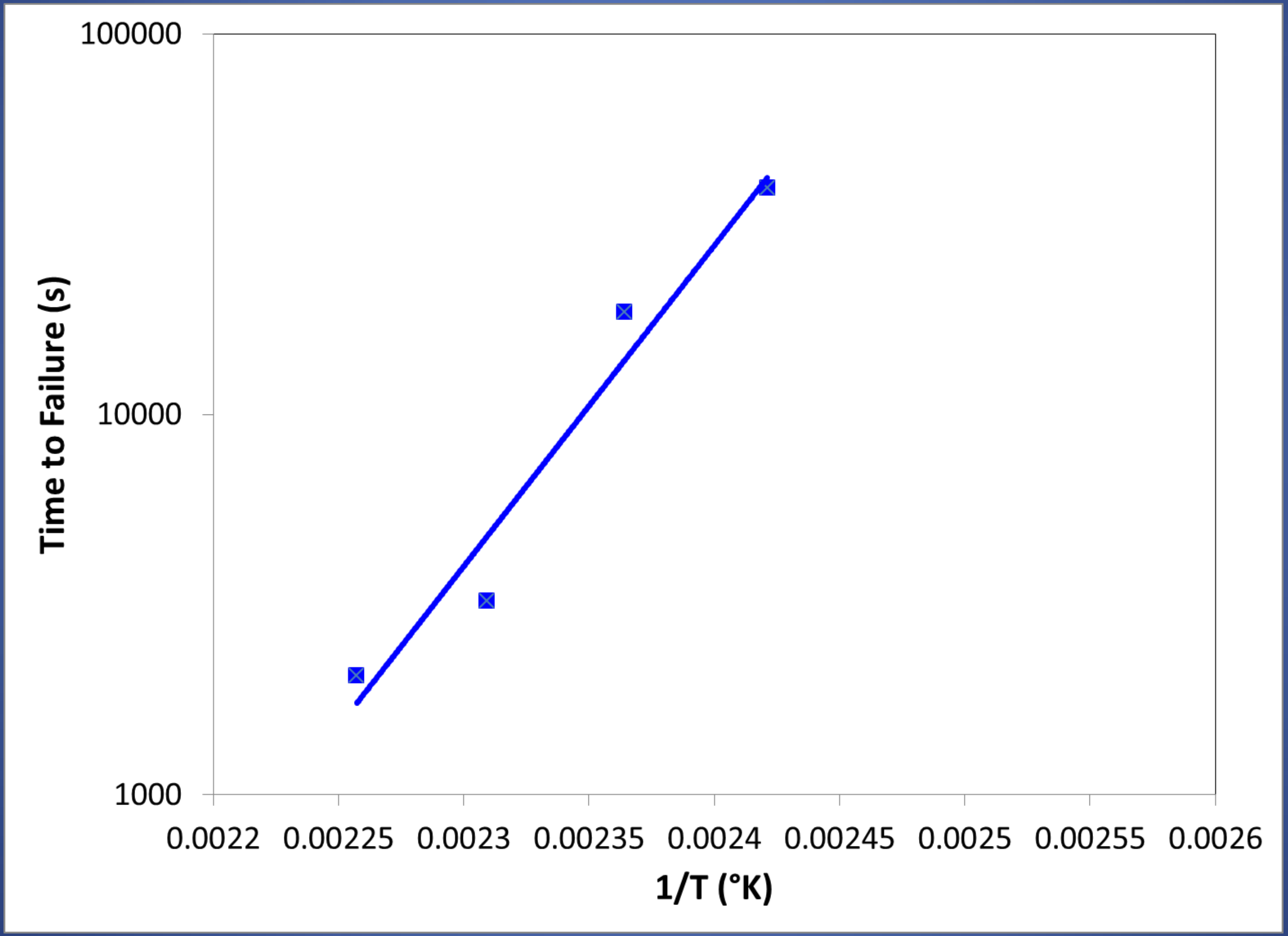
Failure in Bend or Coil Test

Cable Materials Arrhenius Testing

Graphical Interpretation of the Arrhenius Plot



Cable Materials Arrhenius Testing
Optical Fiber Coating

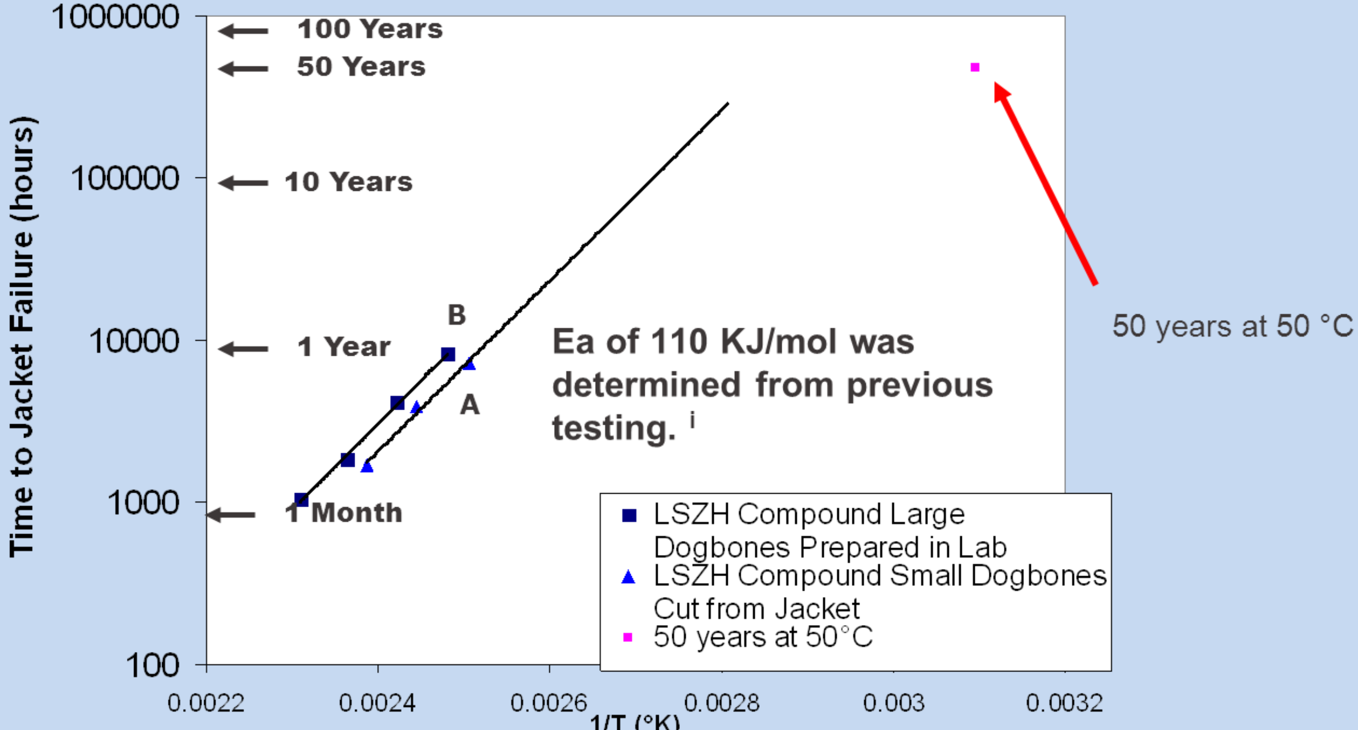


Determination of LSZH Arrhenius Life

Arrhenius Plot for LSZH Cable Material:

A: LSZH Compound tested to 50% ultimate elongation with large dogbones prepared in the lab.

B: LSZH Compound tested to 50% ultimate elongation with small dogbones cut from cable jacket.



[i] Brian G. Risch, Shawn Fox, and Richard A. van Delden, "Lifetime Prediction of Fiber Optic Cable Materials for Nuclear Power Applications: Evaluation of Failure Mechanism, End of Life Criteria, and Test Methodology", *59ht International Wire and Cable Symposium Proceedings*, (2010) 183-191.

Thermal Data, LSZH

Performed T&E testing on LSZH buffer and jacket materials, with outstanding results

Material	Condition	Tensile	Elongation
LSZH	Unaged	100%	100%
LSZH	200+ Yr, 50C	90%	80%

No problem with LSZH material for life well in excess of application

Radiation Data, LSZH

Performed T&E testing on LSZH buffer and jacket materials, with outstanding results

Material	Condition	Tensile	Elongation
LSZH	Unaged	100%	100%
LSZH	102 kGy	134%	143%

Radiation to 10 Mrad had no deleterious effect on LSZH material

Sequential Radiation and Thermal Data, LSZH

Performed T&E testing on LSZH buffer and jacket materials, with outstanding results

Material	Condition	Tensile	Elongation
LSZH	Unaged	100%	100%
LSZH	102 kGy, 60+ Yr @ 50C	114%	125%

Radiation to 10 MRad for 60 yr, 50C equivalent had no deleterious effect on LSZH material

IEEE 1202 Flame Test Results

Sequential Thermal Lifetime Followed by Irradiation Lifetime Simulation

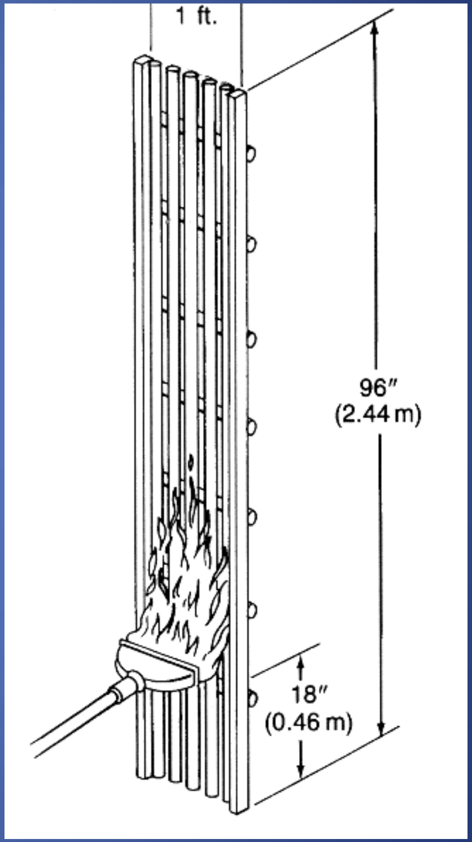
	Unaged Cable 1	**Unaged Cable 2**	**Sequential Thermal Lifetime Simulation +20KGy Exposure**
Time to Ignition (s)	0:11	0:12	0:05
After flame (min)	4:45	3:21	4:47
Cable Damage	Melt: 3’6” Char: 1’11” Ash: 6”	Melt: 3’0” Char: 1’6” Ash: 5”	Melt: 3’6” Char: 1’10” Ash: 6”
Pass/Fail	**Pass**	**Pass**	**Pass**
Peak Smoke (m^2/s)	0.001353	0.001629	0.000293
Total Smoke (m^2)	0.94863	1.395884	1.34301

Result: Both the control and sequential thermal lifetime and irradiated cables passed the IEEE 1202 burn test.

Flame Test Conclusions

All Prysmian fiber optic cables for nuclear plants meet the requirements of IEEE 383, IEEE 1682 and UL 1202

- ✓ Performed in accordance with IEEE 1202-2006 (IEEE 383-2003)
- ✓ Testing done on new and aged samples



Seismic

Seismically tested fiber optic cable assemblies, both duplex and simplex, at Trentec, Cincinnati, OH (2009)

Tested items included: Draka S690T breakout cable, Radiant ST connectors, and Fibraconn patch panels.

Subjected to 6 seismic events (5 x OBE 1 X SSE), monitoring attenuation via a power meter throughout each event.

Result: Assemblies passed, with very limited (<0.1 db, most <0.05 db) variation in received power.

Prysmian Cable EQ Summary

Prysmian nuclear cables have been successfully tested for:

- ✓ Optical Fibers: Exposure up to 200 Mrad
- ✓ Fiber Coating: Thermal and radiation
- ✓ LSZH Materials: 60 yr@ 50C, 10 Mrad (sequential)
- ✓ Cables: Flame testing IEEE 1202, 383, 1682 flame test, unaged and sequentially aged
- ✓ Seismic

Fiber Optic Cable Condition Monitoring

Fibers characteristics can be directly measured by having access to one or both ends of a cable run

Two methods

1. **Periodic measurement**
2. **Continuous (real time) measurement**

Periodic Monitoring

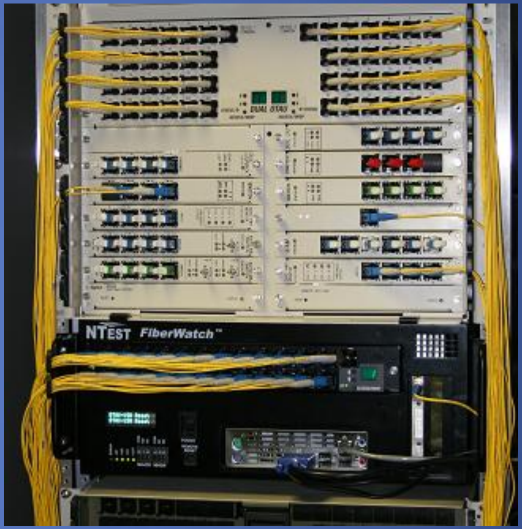
Periodically use an OTDR (which requires access to only one end of the cable) to measure power loss. This method also produces a graphical interpretation of the total cable loss.

Perform scheduled maintenance of a regular basis using a power meter (which requires access to both ends of the cable run)

Continuous Monitoring

A fiber optic cable can be monitored continuously with an OTDR.

Using an OTDR with an optical switch, multiple fibers can be monitored in real time and loss measurements can be logged.



One commercially available system can be set to alarm or send a notice of an unusual event when a predetermined loss is reached, all done from a central location using live or spare

Thank You!

Questions?