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Long term life of Nuclear Fiber Optic Cables

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Outline

Background – Accelerated Test Models

Draka Optical Fiber Studies
- **Literature**
- **Performance**

Draka Cable Materials
- **Cables and Materials**
- **IEEE Testing Standard & IAEA-TECDOC-1188**
  Procedure and Example Performance
  Planning

Conclusions

Accelerated Test Methods

Required for reliability predictions

Use accelerating variables (temperature, radiation dose, wear and vibration) at elevated levels to estimate longer time and use levels

Modeling has improved accuracy if failure modes are known through experience

All accelerated test methods are based on extrapolation, using a reasonable statistical model:

- Arrhenius
- Weibull
- Eyring

Statistical Accelerated Models

Two major types:

1. Physical – the failure can be described based on physical or chemical theory (i.e., polymer crosslinking, oxygenation, crack growth, loss of material strength)

2. Empirical – based on data only. Risk is that the results defy reality and have no physical meaning

Sample planning and test setup are critical causing risks:

a. Test all samples at elevated conditions with no failures – may not give meaningful results

b. Not all the samples fail

Optical Fiber Reliability

Fiber Reliability Model – Nuclear Applications

More mature understanding compared to cable materials

Mechanism well established – radiation induced attenuation (RIA)

Radiation mechanism

“Photobleaching”

RadHard Single Mode Fiber (SMF) – high data rates over long distances

RadHard Multimode Fiber (MMF) – Short distance/Datacom

Fiber Use in Radiative Environments

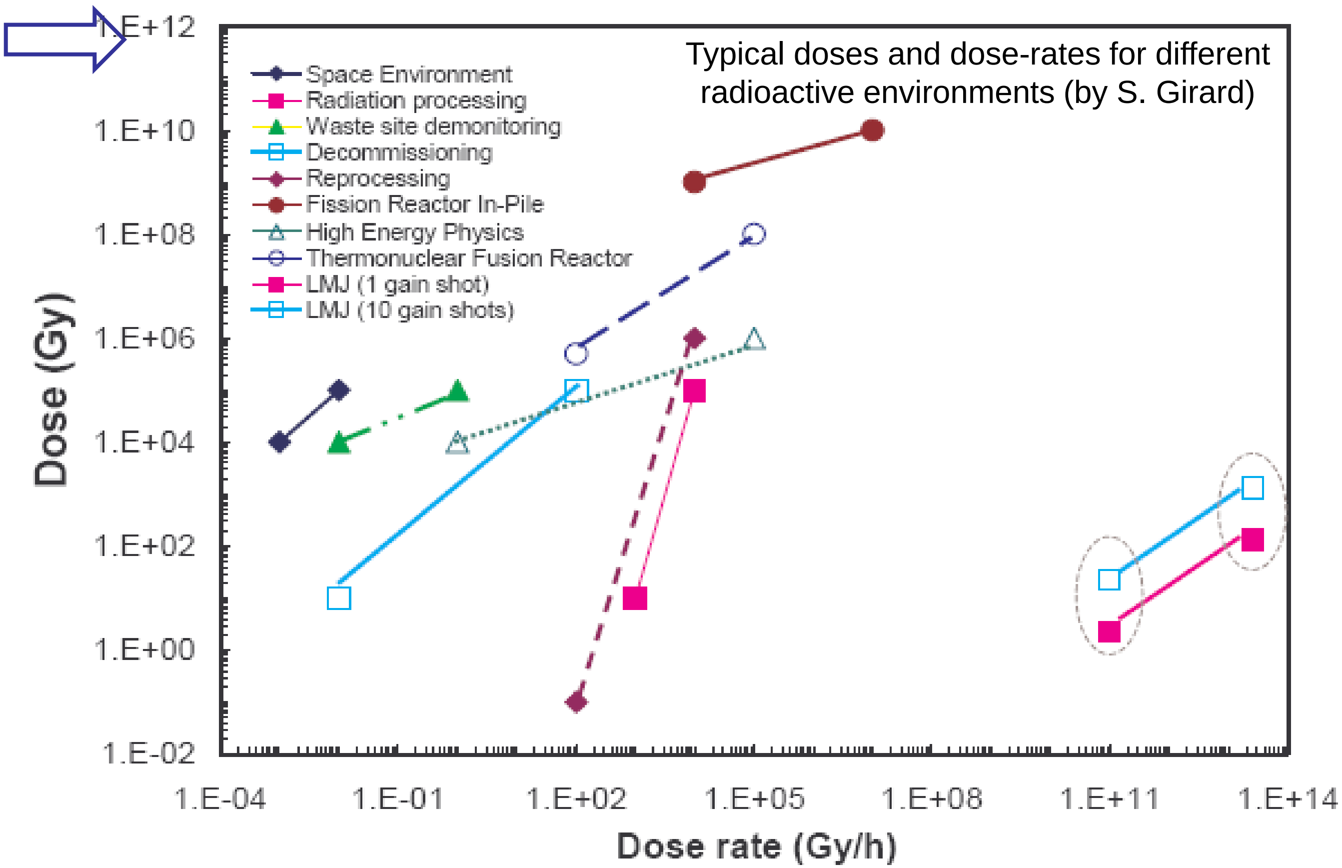
Radiative environment:

- Nature of radiation
- Total dose

  (in Gy (1Gy = 100 Rad))
- Dose-rate

  (in Gy/ time unit)

Remark: some applications can have low doses but high dose-rates (ex: LMJ).



1 Gy = 100 Rad

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Fiber Use in Radiative Environments

		Doses	Dose-rates	Typical applications
Military* & *protection of strategic civil data*		**From a few mGy up to 10^2 - 10^3 Gy**	**From 10 Gy/h up to 10^9 – 10^{13} Gy/h (pulsed irradiations)**	**Data transfer**
Space		**From 10 up to 10^4 Gy**	**From 10^{-2} up to 10^2 Gy/h**	**Data transfer, gyroscopes**
Nuclear power plants	Normal **40°C**	**~5.10^5 Gy (over 40 years)**	~1 Gy/h	**Tele-operation (up to 10^5 Gy/h), data transfer, fiber sensors**
	Accident **120°C**	**~ 10^6 Gy**	~10^3 Gy/h	
High Energy Physics laboratories (CERN-LHC)		**< 10^5 Gy (annual total dose)** **Up to 10^6 Gy (future equipments)**	**< 1 Gy/h** **Up to 10 Gy/h**	**Data transfer, fiber sensors**

*: no official data

* Irradiative environments (= critical domains) ⇒ **Safety** and **reliability**!!
* Very important to well know the behavior of optical fibers under radiations.

Fiber Use in Radiative Environments

Many studies on this topic for 25 years ⇒ quite a good knowledge

* Main critical point: attenuation increase (Radiation-Induced Attenuation or RIA)

⇒ See next slides

* Other potential changes in fiber properties

° Mechanical properties ⇒ acrylate coated fibers: no effect observed up to at least **2 MGy** [Semjonov – 1997]

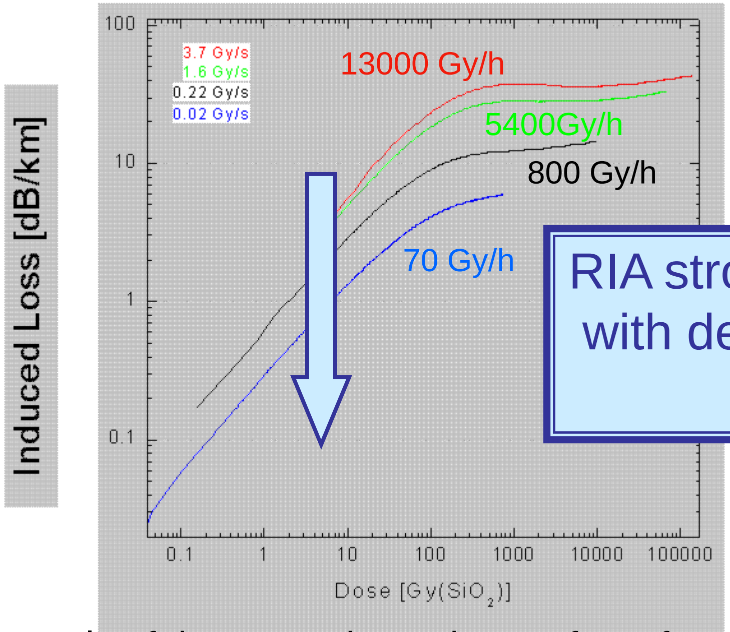
➔ Today, we are aware that it is very important to choose the most appropriate fiber (the nature of which depends on the application), clearly define the acceptable loss budget (including the whole optic system) and the irradiation conditions.

➔ Preliminary γ-radiation tests give an idea of fiber radiation-resistance.

Fiber Use in Radiative Environments

* Under radiation, fiber attenuation increase depends on radiation conditions:
➔ total dose, dose-rate, temperature, injected power, etc…

Dose-rate dependency:



RIA strongly decreases with decreasing dose-rate!

Example of dose-rate dependency of RIA for a fiber of Pure Silica type
(extracted from Kuhnhenn's presentation - 2005, on CERN website: http://indico.cern.ch/conferenceDisplay.py?confId=a056455).

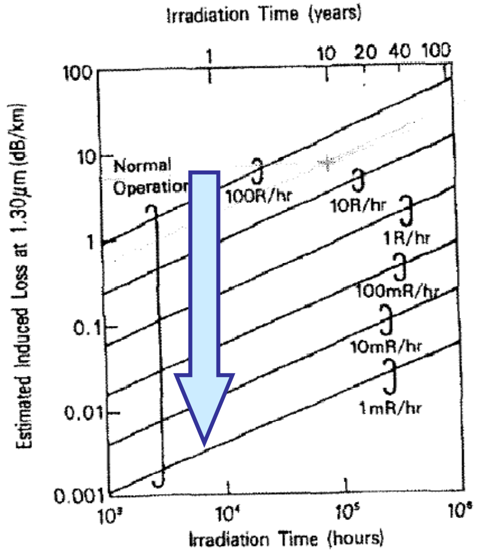


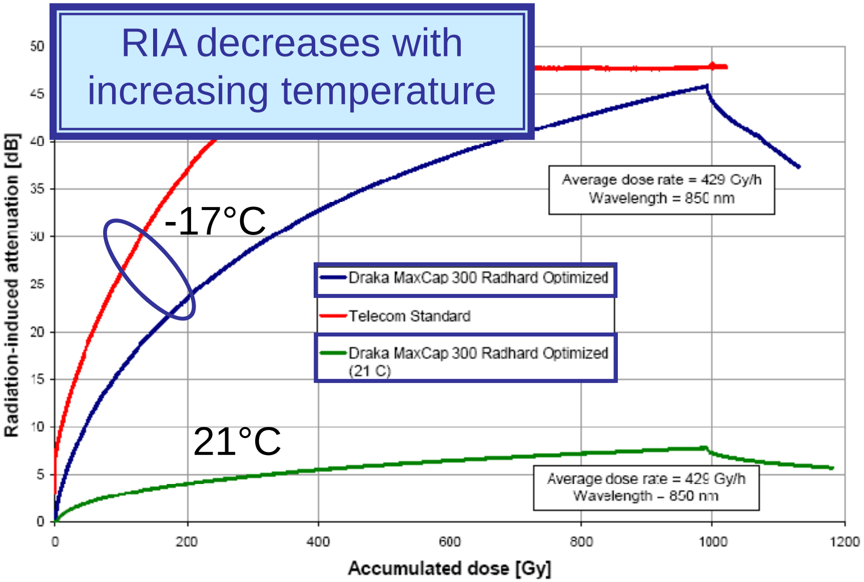
Fig. 5. Estimated total dose dependence of induced loss.

Extracted from Kyoto – 1992.

Fiber Use in Radiative Environments

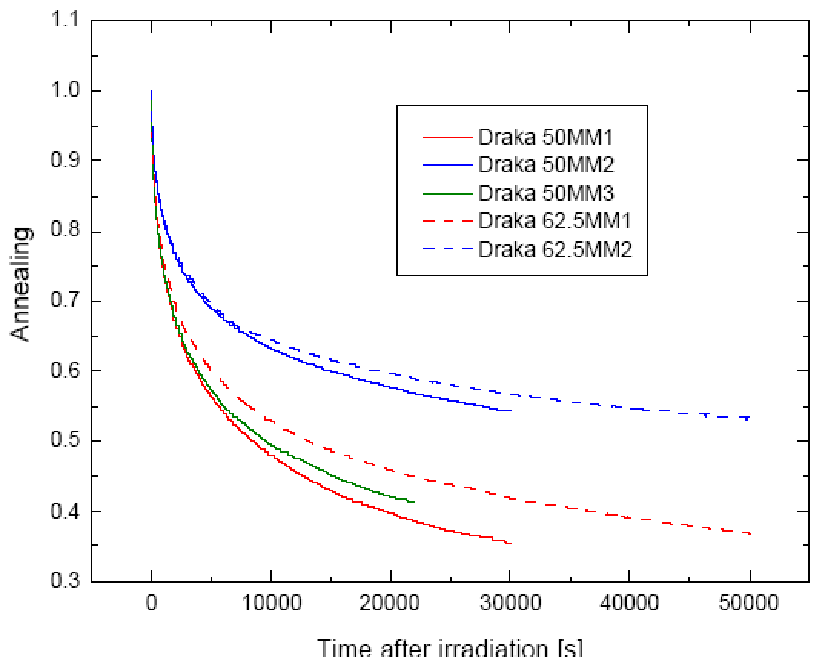
* Under radiation, fiber attenuation increase depends on radiation conditions:
➔ total dose, dose-rate, temperature, injected power, etc…

Temperature dependency



Example of **temperature** dependency of Radiation-Induced Attenuation (RIA) for MMF fibers
(extracted from S. Theriault's – Photonics North 2006, Quebec).

Annealing after radiation

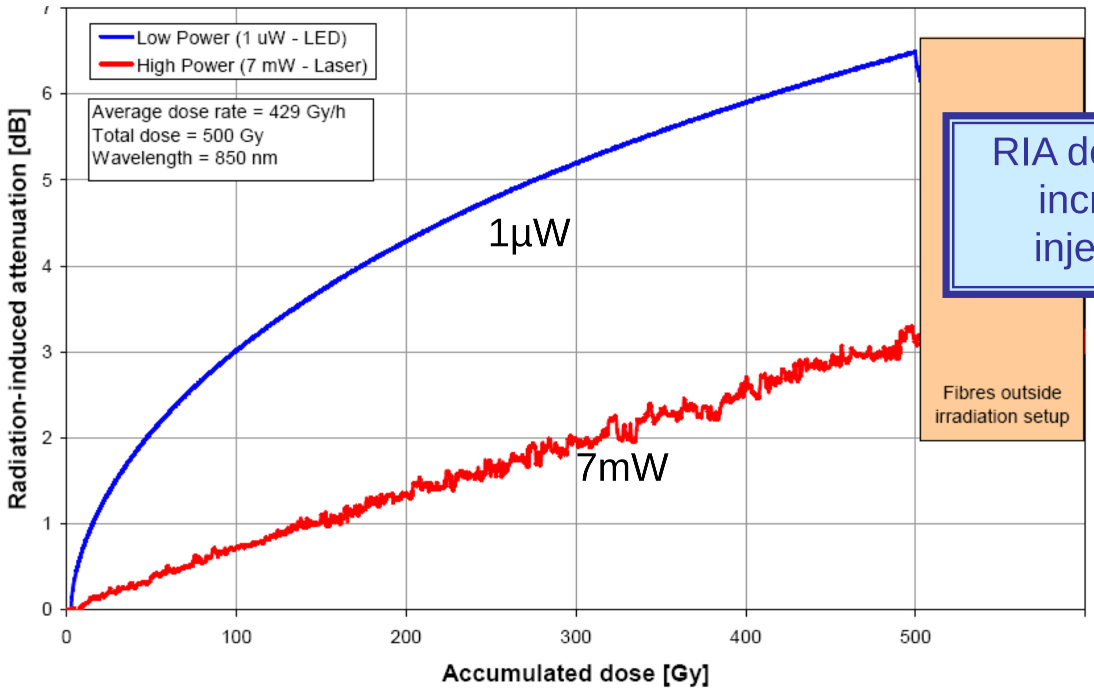


Example of RIA annealing for MMF fibers

Fiber Use in Radiative Environments

* The Radiation-Induced Attenuation (RIA) strongly varies from a fiber to another. Also the attenuation level after the radiation exposure, and both dose-rate and temperature dependencies strongly vary.

RIA dependency with injected power or Photobleaching



RIA decreases with increasing the injected power

Example of RIA dependency with **injected power (photobleaching)**
(extracted from S. Theriault's – Photonics North 2006, Quebec).

Fiber Use in Radiative Environments

* Radiation-Induced Attenuation or RIA

- **Impact of radiation conditions:** dose-rate, total dose, temperature, nature of radiation

  [Van Uffelen, Kyoto, Griscom, Henschel, West]

  ° **RIA _generally_ increases with increasing dose and dose-rate, but decreasing temperature.**

  ⇒ *Take care of comparing only RIA curves that have been obtained exactly in the same conditions!*

  ⇒ *Be aware that accelerated gamma-exposures (i.e. at higher dose-rates than the final operating dose rate) will lead to much higher RIA. However, such trials can be very useful for fiber comparison.*

  ⇒ *Try to make the preliminary radiation-tests with conditions as similar as possible to the final in-situ radiation conditions.*

  ° **Nature of radiation (gamma, neutron, X, etc.) => seem to lead to quite comparable results (for same doses).**

  ⇒ *Note that ^{60}Co sources are the easiest to use. Many radiation facilities (Fraunhofer Institute, INO, Tecnologica, CEA)*

Optical Fiber Summary

Radiation Induced Attenuation – IMPACT of Fiber Manufacturing:

1. **Fiber coating – at high doses, can be critical**

   Radiation can cause crosslinking resulting in microbending

2. **Residual Impurities – keep low**

   Alcaline, metallic impurities result in poor performance

3. **T_f – fictive temperature – keep low**

   Minimizing the fictive temperature of the glass minimizes the number of glass defects

4. **OH and Cl content – depends on operating wavelength**

Draka Nuclear Cable Materials (non-Fiber)

Nuclear Cables Recently Produced at Draka:

LSZH breakout:

- Tight buffers
- Components with strength membe
- Overall LSZH Jacket

Plenum rated breakout:

- Same as above but with plenum rated components

Indoor/outdoor Loose Tube

- Multiple fibers in gel-filled tubes
- Appropriate # of tubes stranded
- Overall LSZH jacket

Draka Nuclear Cable Materials (non-Fiber)

Test Strategy:

1. **Aging tests on material (bulk)**
2. **Cable aging tests as complete product**
3. **Verification testing (combine T and radiation)**

Components

Gel (loose tube only)	**Mastergel**
Buffer Tubes	**PBT**
Tight Buffer	**Hytrel 5555HS or PVDF for plenum**
Strength Members	**Fiber Reinforced Polymer (FRP)**
	Central Strength Member
	Aramid strength elements
Jackets	**LSZH or PVDF plenum**

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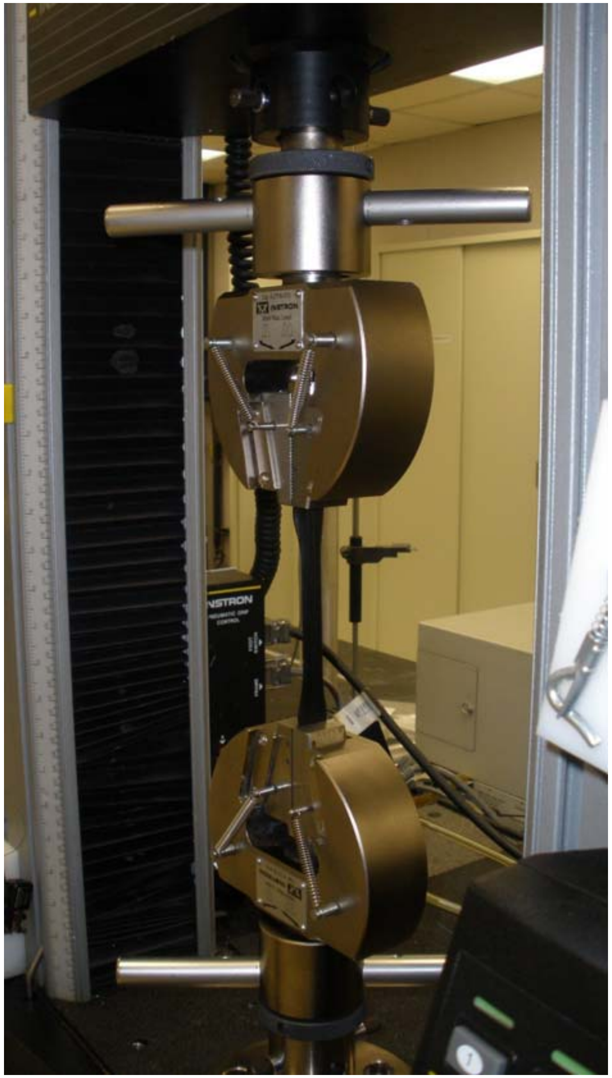
Draka Nuclear Cable Materials (non-Fiber)

Test Strategy:

1. **Aging tests on material (bulk) – tensile test samples**
2. **Cable aging tests as complete product – mandrel wrap, indentation testing**
3. **Thermal analysis samples (TGA, OIT)**
4. **Verification testing (combine T and radiation)**

Draka Nuclear Cable Materials – Materials Characterization Facility



Jacket Elongation using Dog-Bone Samples

Buffer Tube Elongation – after aging with gel

Strength Yarn Elongation

Gel – after aging, test for OIT

TGA, DTA, OIT, SEM available

Nuclear Cable Materials – Lifetime Testing Procedure

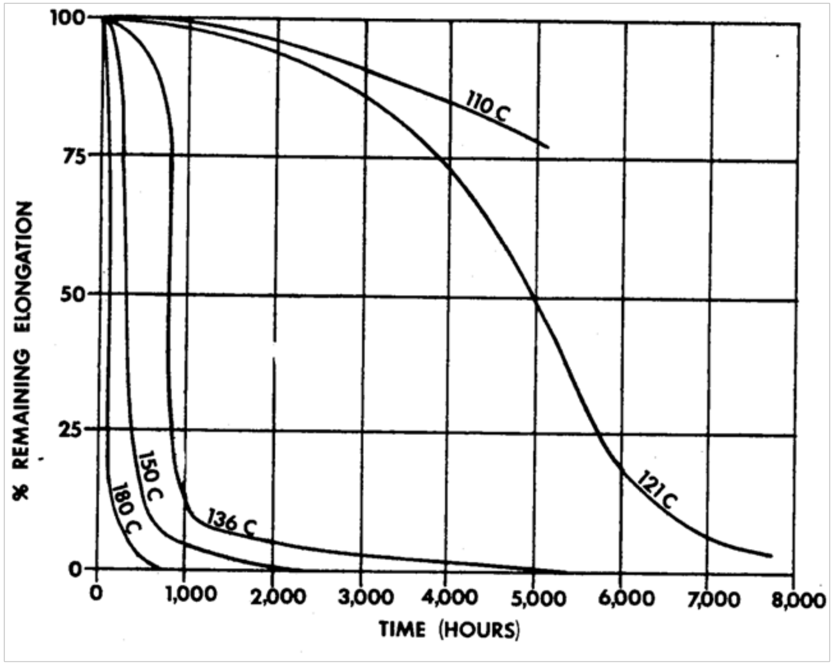
Arrhenius Method $A\ (time) = A_o e^{(-E/kT)}$

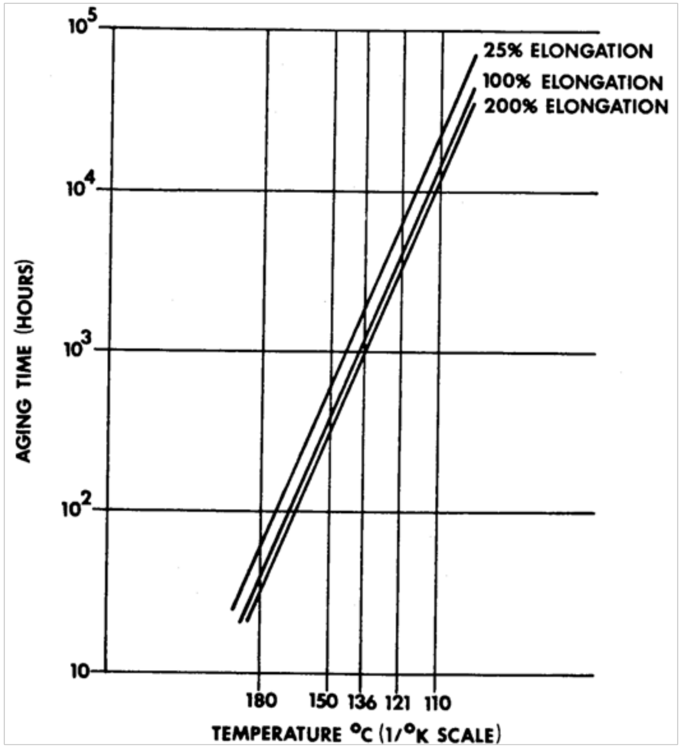
- **A = Acceleration Coefficient**
- **E = Activation energy of rate controlling mechanism**
- **k = Boltzman constant**
- **T = Temperature (Kelvin)**

For Jacket, Buffer Tube Materials – use elongation response (most common):

1. **Choose at least 3 temperatures**
2. **Age material for different times (1,000's of hours)**
3. **Measure % Elongation (dogbone-Instron testing)**
4. **Plot log time vs 1/T at constant elongation to determine the activation energy of the process – extrapolate to use conditions.**

Draka Nuclear Cable Materials – Baseline Materials Characterization





Arrhenius modeling of % elongation of jacket material complete at Draka (BIW) on Bostrad^{7E} cables. The rate of aging determination allows a line to be extrapolated through the desired service condition.

Draka Nuclear Cable Materials – Baseline Materials Characterization

Follow-up Testing:

Cables aged in an accelerated fashion can be verified for performance through the following tests:

Mandrel wrap – check the material for any cracking, damage for a 20X OD bend

Verification – cable samples should be tested as a unit through accelerated aging to verify performance

Coupling aging with radiation testing

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Conclusions

1. **Long term reliability studies are Required for Optical Fiber Cables in Nuclear Power Plants – both fiber and cable materials**

   Draka has and will continue to do this testing

2. **Continued experimentation is required to improve our physical understanding of acceleration rate steps in our nuclear cables**

   following IEEE P1682/D1b protocol

3. **New computer models are being developed to enhance simplified Arrhenius approaches to lifetime reliability**

   Sandia Labs

   Oak Ridge National Lab

   Lawrence Livermoore National Lab

4. **Establish performance for 80 year cable system life (EPRI – 2008)**

   "Nuclear Plant Cable Aging Management" – G. Toman

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Thank you for your attention