Optical Fiber Behavior in Radioactive Environments

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Advantages of Fiber Optic Systems

- Electromagnetic immunity
  - ➔ no cross talk between adjacent fibers
  - ➔ direct contact with high voltage electrical equipment and power lines / no ground loops of any kind
- Low attenuation, large bandwidth
  - ➔ much higher data rates / ability to carry much more information and deliver it with greater fidelity than either copper wire or coaxial cable
- Ideal for secure and safe communication systems
  - ➔ very difficult to tap but very easy to monitor / no possibility of a spark from a broken fiber.
  - ➔ even in the most explosive atmospheres, there is no fire hazard
- Chemical stability
  - ➔ impervious to corrosion / buried directly in most kinds of soil or exposed to corrosive atmospheres
- Low weight, low volume
  - ➔ much smaller than a wire / coaxial cable with similar information carrying capacity
  - ➔ easier to handle and install, and uses less duct space

Improvement of Fiber Properties

- Attenuation reduction

  ➔ presently: <0.2dB/km @1550nm

- Strong increase of information-transmitting capacity

  ➔ Wider Wavelength range, Higher Data Rates/Laser Optimized

- Good mechanical resistance

  ➔ Lifetime > 25y; mainly mankind failures

- Large fiber production volumes

  ➔Stabilization of fiber features & standards

- Radiation Resistance Performance Understanding

Uses of Optical Fiber in Radiative Environments

- Military

  no official data - classified; certifications (USA: MIL-PRF 49291)

- Nuclear Power Plants

- High Energy Physics Laboratories

  CERN (Geneva)
  Fermi National Accelerator Lab. (USA)

- Space industry

  NASA / ESA

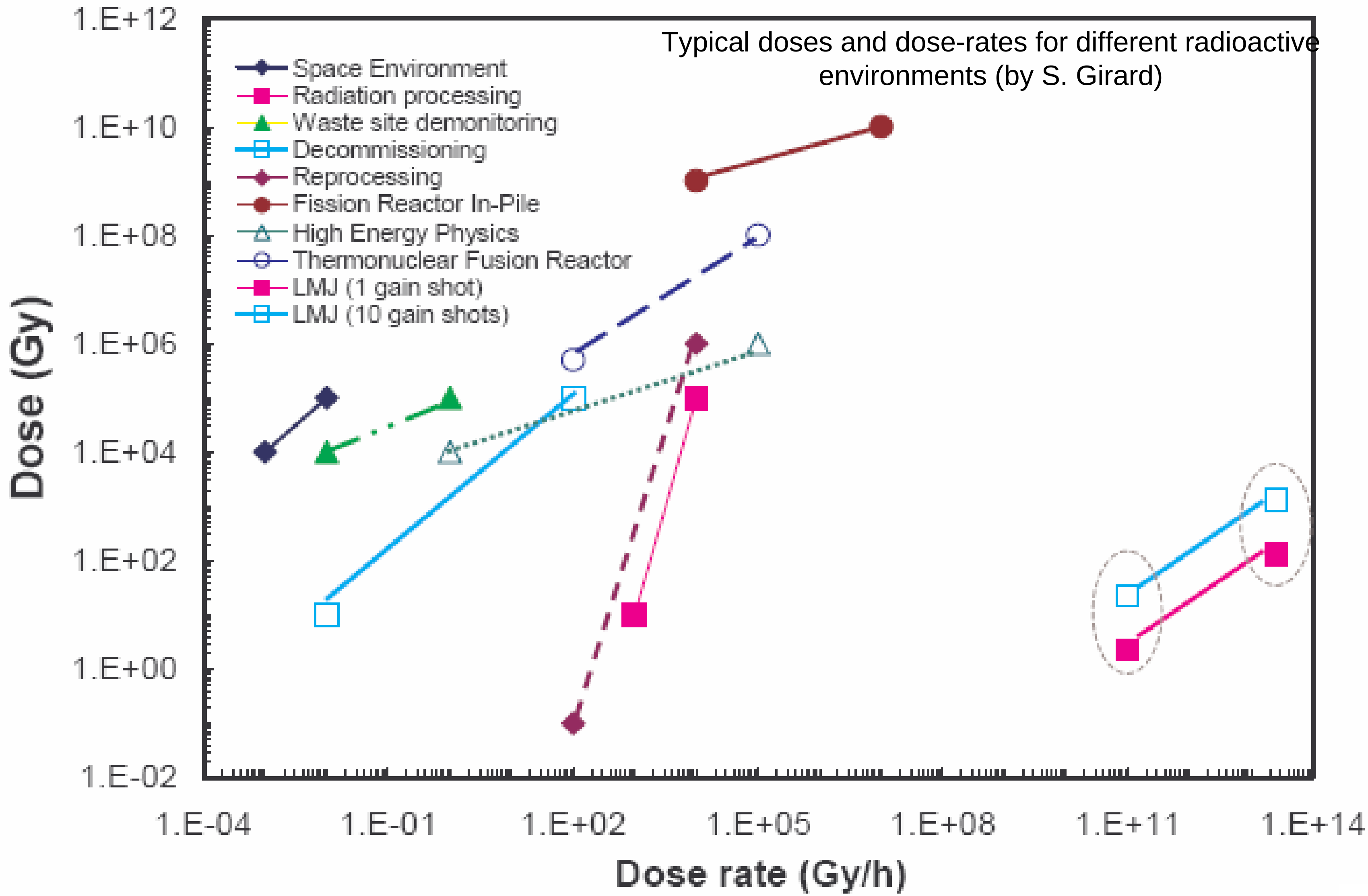
1 Gy = 100 Rad

Uses of Optical Fiber in Radiative Environments

		Doses	Dose-rates	Typical applications
Military ***& protection of strategic civil data (estimated – no official 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

1 Gy = 100 Rad

Uses of Optical Fiber in Radiative Environments



1 Gy = 100 Rad

What kind of fiber to choose?

Single mode fibers (SMF)

High data rates over long distances

- **➔ Current RadHard: SMF G.652 (MIL qualified: MIL - PRF- 49291/7)**

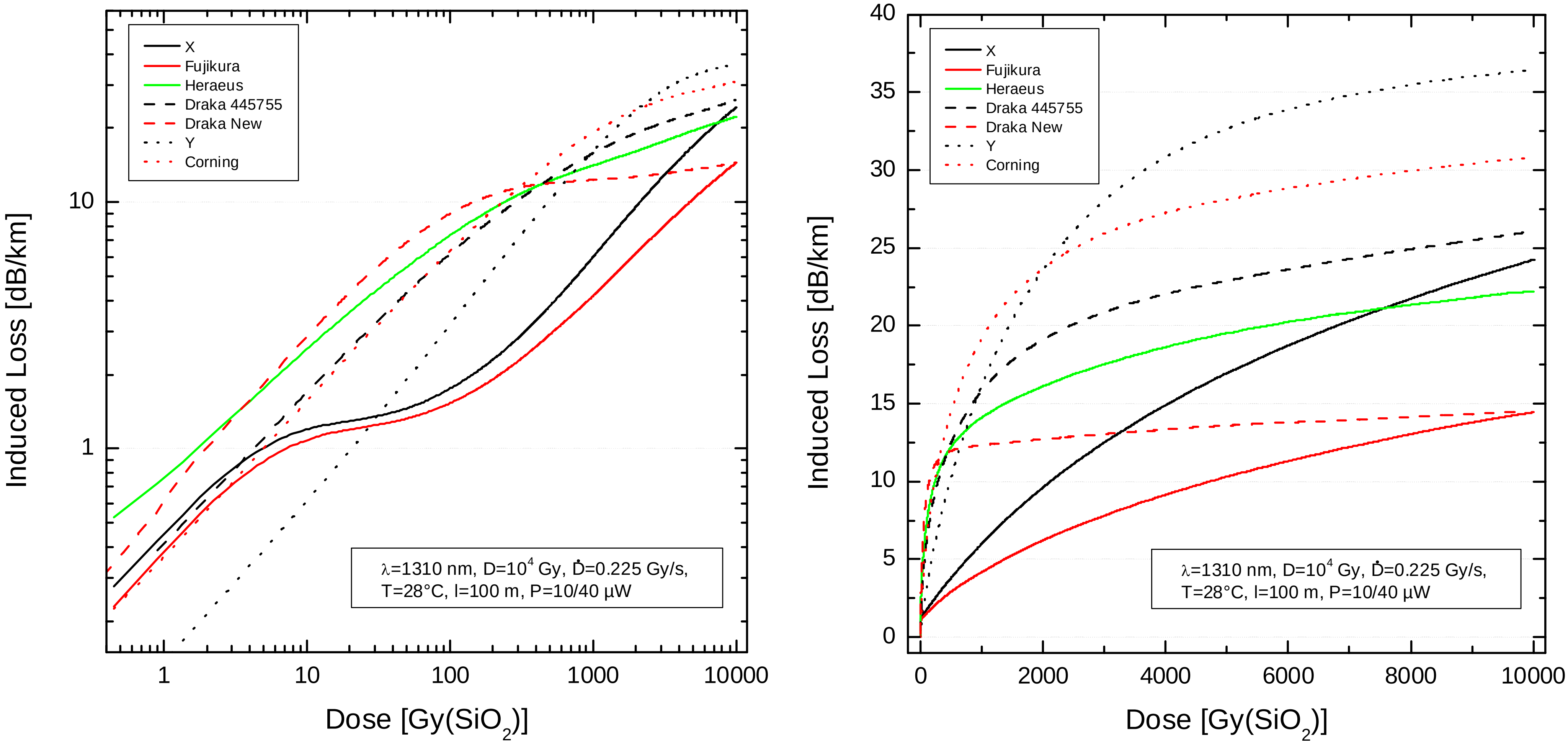
Multimode fibers (MMF)

Short distance / Datacom

- **➔ Current: 50 µm OM2 RadHard (MIL qualified: MIL - PRF - 49291/1)**
- **➔ Current: 50 µm OM3 RadHard (10Gb/s over 300m @850nm)**
- **➔ Current: 62.5 µm OM1 RadHard (MIL qualified: MIL - PRF - 49291/6)**

1 Gy = 100 Rad

Comparison of different commercial SMFs tested



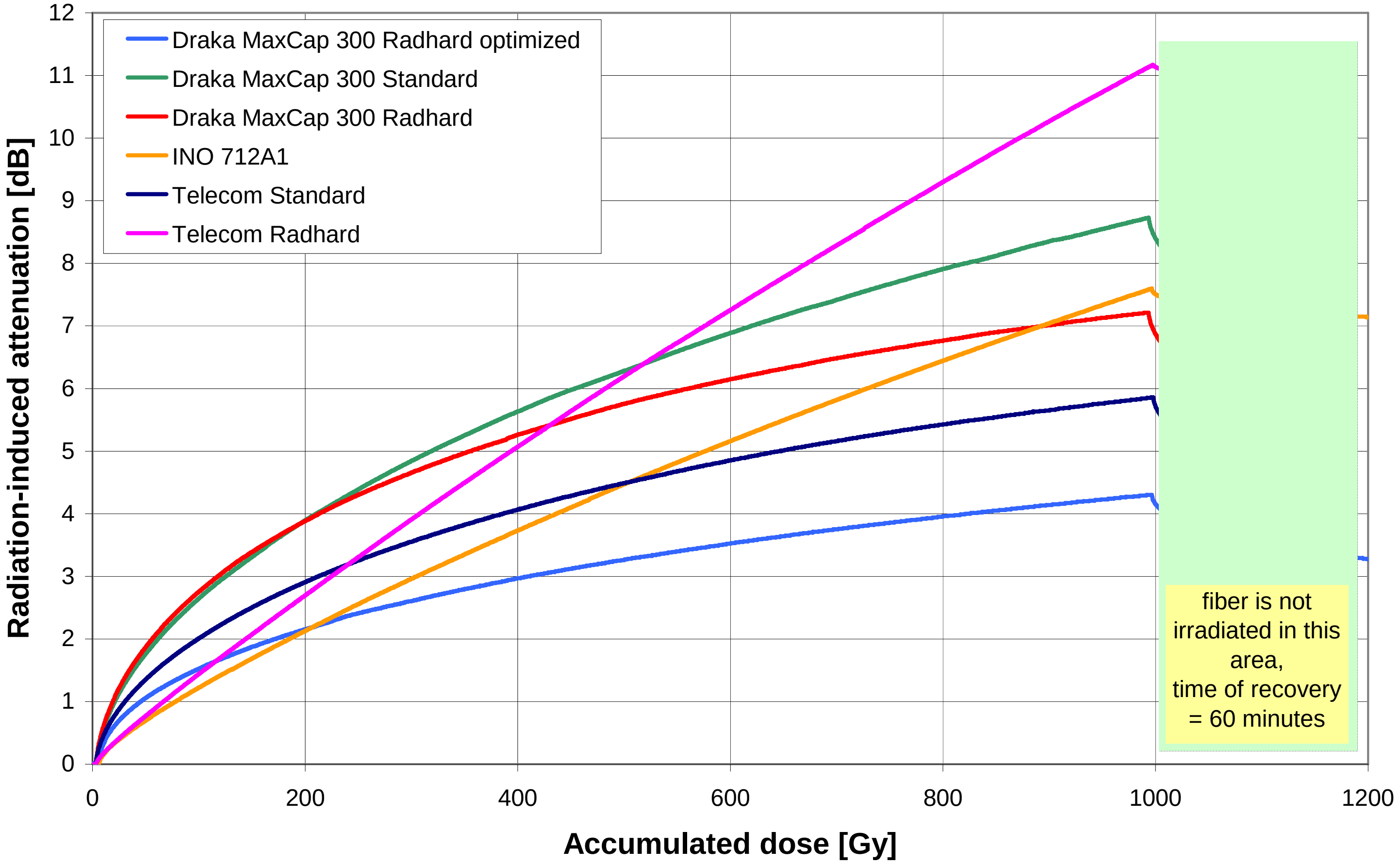
Radiation-Induced Attenuation for different commercial SMFs – by Fraunhofer Insitute

1 Gy = 100 Rad

50/125 µm MultiMode Fiber behavior

Comparison of different commercial MMFs tested for ESA by INO

Radiation-induced attenuation in some COTS fiber samples (100 metres)
Average dose rate = 157 Gy/h, Total dose = 1000 Gy

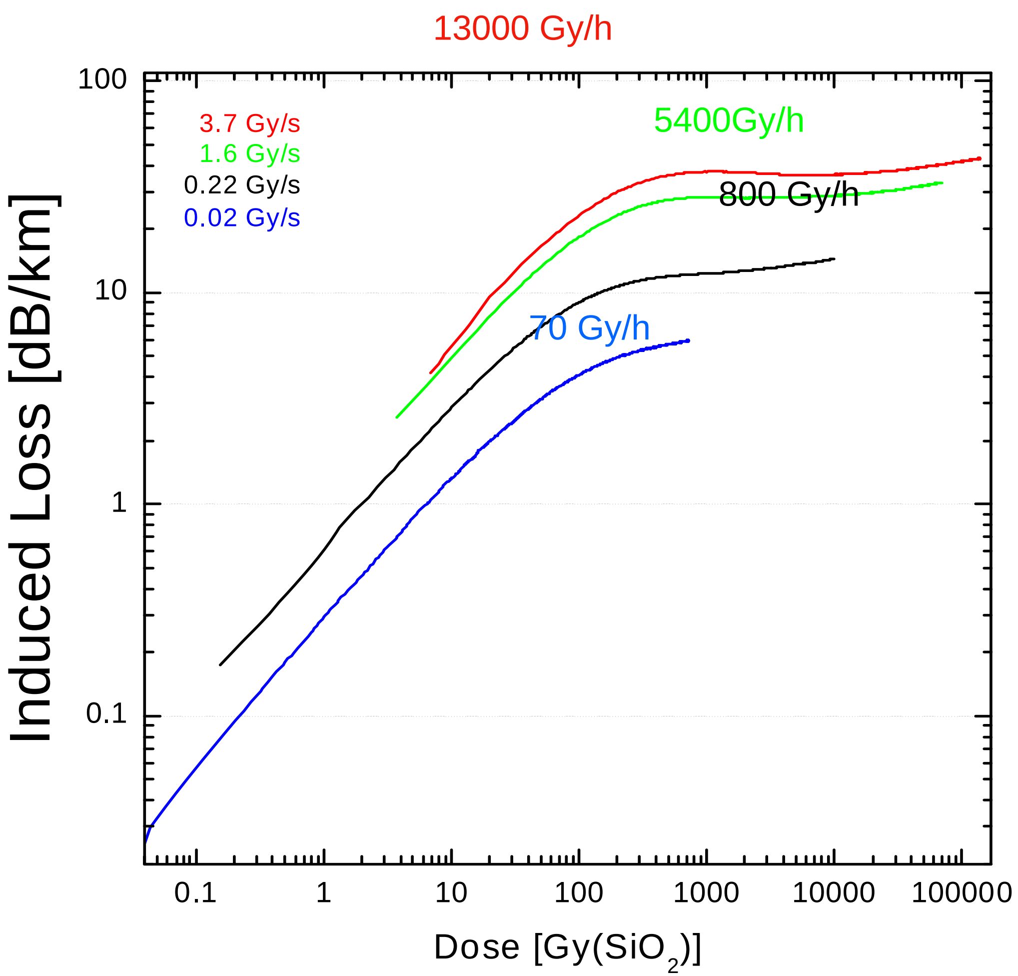


Draka-MaxCap 300 RadHard optimized: recommended for space appl. [Theriault – 2006]

[Thériault, INO, Canada - 2006]: "Radiation Effects on COTS Laser-Optimized Multimode Fibers Exposed to an Intense Gamma Radiation Field", by S. Thériault, Conference Photonics North 2006 – Quebec city, *June 2006*

1 Gy = 100 Rad

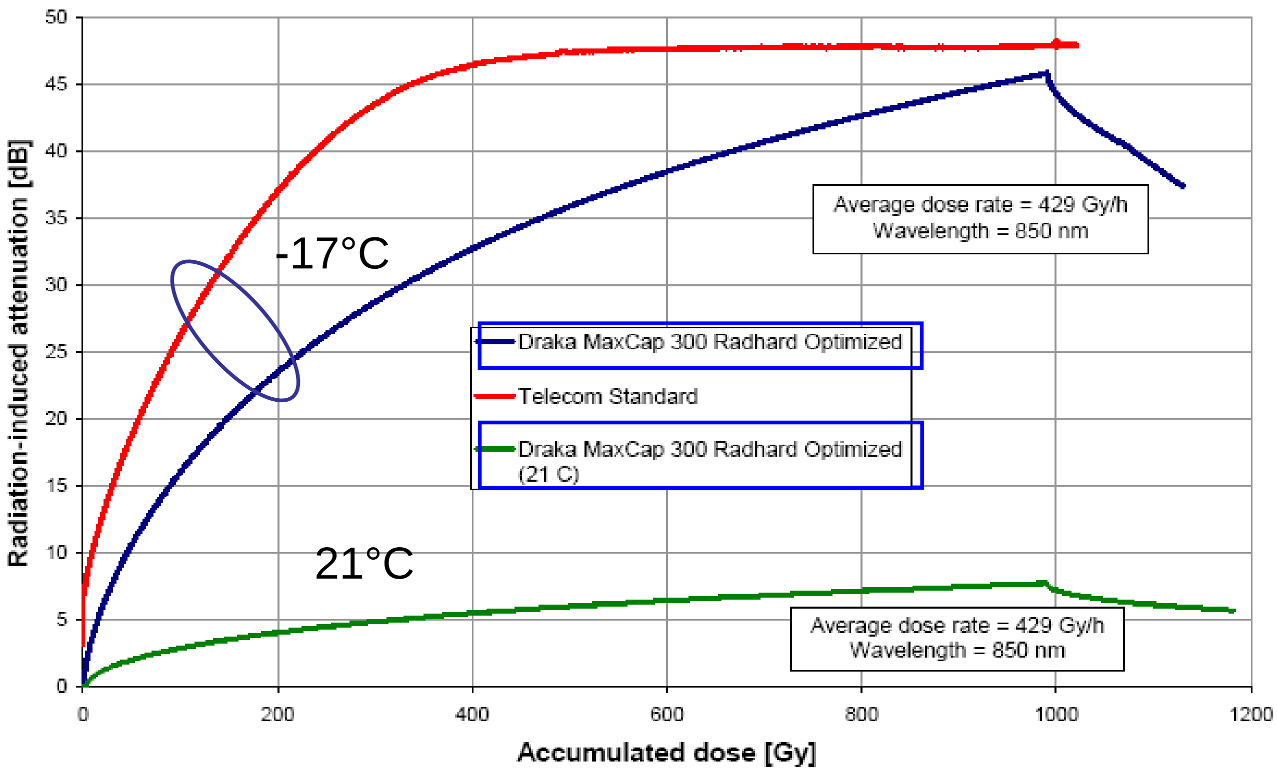
Dependence on Dose Rate



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).

1 Gy = 100 Rad

Dependence on Temperature

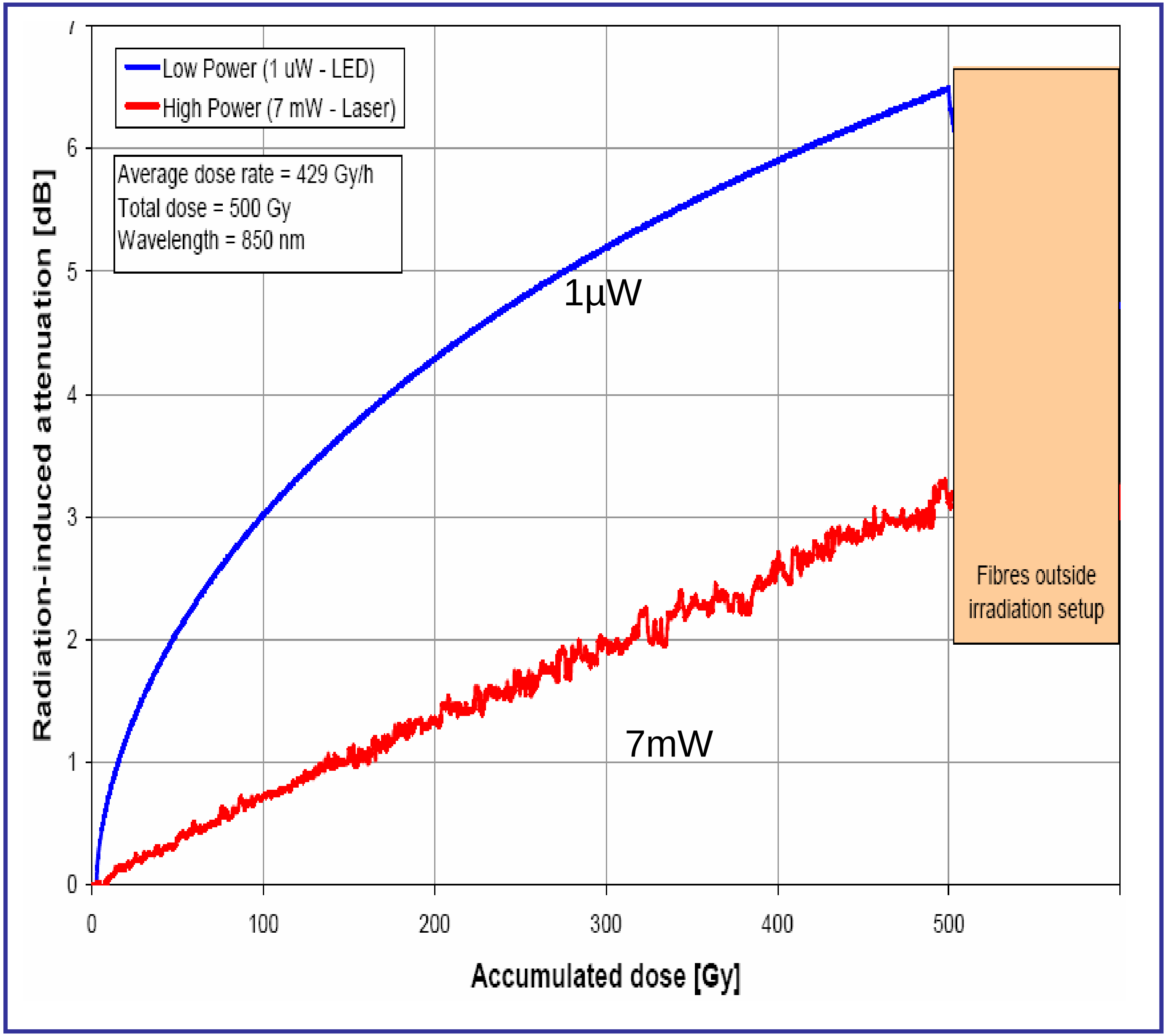


Example of **temperature** dependency of Radiation-Induced Attenuation (RIA) for MMF fibers

(extracted from S. Theriault's – Photonics North 2006, Quebec).

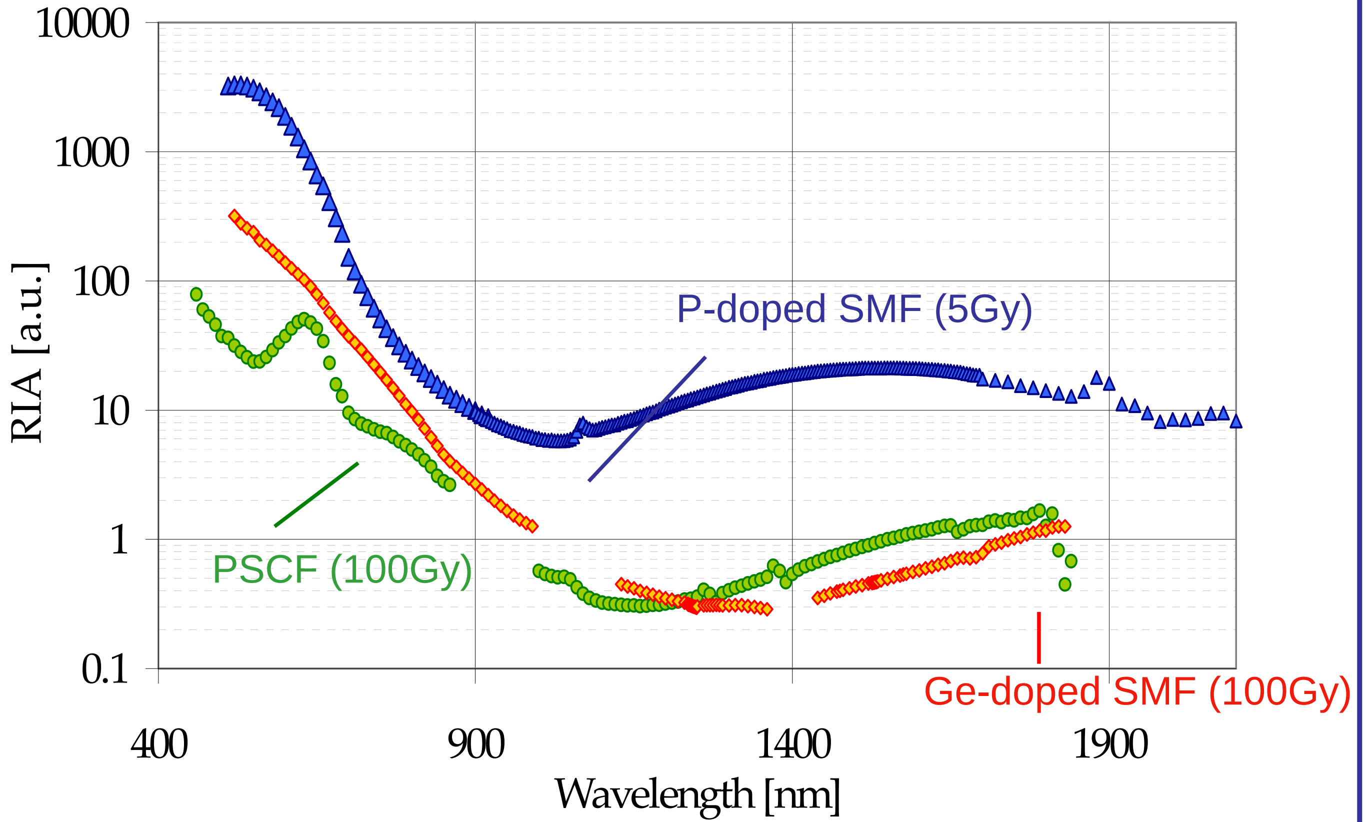
1 Gy = 100 Rad

Dependence on Injected Power



1 Gy = 100 Rad

Dependence on Fiber Composition



1 Gy = 100 Rad

Radiation-Induced Attenuation or RIA

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

RIA *generally* increases with increasing dose and dose-rate

⇒ *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)*

RIA *generally* increases with decreasing temperature

1 Gy = 100 Rad

What we have learned

Radiation-Induced Attenuation or RIA

- **Impact of dopants/Fiber Composition:**

Do not use P and B as dopants

Formation of Phosphorus-defects that have strong absorption bands;

one of them is located in the NIR => very bad for uses at 1310nm and 1550nm

At very high doses (~MGy), use pure silica instead of Ge-doped fibers

Ge-doped fibers: formation of Ge-defects (GeE’, Ge(1), Ge(2), GEC)

- **Impact of manufacturing conditions:**

Coating: can be critical at high doses

Radiation can cause crosslinking resulting in microbending

– Special Coatings

1 Gy = 100 Rad

More work to be done!

Effect of Radiation on Fiber Mechanical Properties

- Strength
- Bending
- Physical Dimensions

Temperature Dependence

Further Comparisons of Fiber Composition and Design

1 Gy = 100 Rad

Summary - Conclusions

- Optical fiber offers important features in radiative environments

- Behavior of optical fiber in radiative environments can be complex

  Dependent on many variables including
  dose rate, temperature, fiber composition and optical power

- Careful characterization of the radiation conditions is important

- Careful selection of fiber is very important, based on allowed loss budget, mechanical porperties and fiber composition

Thank you for your kind attention !

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