Radiation Effects on COTS Laser-Optimized Multimode Fibers Exposed to an Intense Gamma Radiation Field

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The SpaceFibre project

- The study “Optical Links for the SpaceWire Intra-Satellite Network Standard” or the SpaceFibre project was initiated by ESA in 2002
- SpaceFibre aims to be the optical fiber extension of the SpaceWire standard
- Shall cover requirements of very high end applications
  - Higher data rates and longer link length
- The SpaceFibre development team:
  - Patria (Finland): Prime, Interface electronics, protocol definition
  - VTT (Finland): Fiber optic transmitter & receiver
  - INO (Canada): Optical fiber
  - Fibrepulse (Ireland): Fiber optic connectors and assemblies
  - Gore electronics (Germany): Optical fiber jacket
  - University of Dundee (UK): SpaceWire protocol

Limitations of SpaceWire

- **SpaceWire link data rate is currently 200Mb/s**
  - **High Resolution SAR, Hyper Spectral Imagers, High Speed High Resolution Cameras produce data at a rate of some Gb/s**
  - **Requires bundling of several SpaceWire links for these instruments**
- **SpaceWire link maximum cable length is 10m**
  - **Jitter and skew between on Data and Strobe signals**
  - **Sufficient for on satellite applications but other applications like Launchers and the Space Station require longer cable length**
- **SpaceWire does not provide galvanic isolation**

SpaceFibre requirements

- **Requirements for the SpaceFibre link:**
  - **Provide symmetrical, bi-directional, point to point link connection based on fiber optic link technology**
  - **Compatibility with SpaceWire**
  - **Minimise mass, power and size**
  - **Scalable, modular**
  - **Reliable operation in space environment**
  - **Data rate: from 1 Gbps up to 10 Gbps**
  - **Link length: > 100 m**
  - **BER: $< 10^{-12}$**
- **The basic requirements for the optical fiber are:**
  - **Radiation hardened**
  - **10 Gbps capacity**
  - **COTS solution is preferred**

The Space environment

- **4 general conditions**
  - **No pressure -> no outgassing materials allowed**
  - **Large temperature variations**
  - **Strong vibrations and shocks at launch and docking**
  - **Presence of radiation (solar flare events, South Atlantic Anomaly)**
- **In this study, focus is on radiation characterization**
- **Standard unit is Gray (Gy), 1 Gy = 100 rads**
- **Typical radiation levels in Space**
  - **Total irradiation dose (TID) starts at 1000 Gy for a typical mission lifetime of 10 to 15 years**
  - **The background dose rate is around 0.06 Gy/h**
  - **The dose rate during solar flare events can be as high as 20 Gy/h**

The first optical fiber requirement: radhard

- Radiation hardness strongly dependent on materials and fabrication processes
  - Phosphorous doping must be avoided
  - Germanium has little impact except at low temperatures
- OH doping
  - Improves greatly radiation hardness and helps the fibre to anneal
  - Limited to step-index fibres
- Radiation-induced attenuation
  - 1300- and 1550-nm bands have lower intrinsic losses compared to 850-nm
  - Proportional to dose rate and total dose
  - Worsens at lower temperatures
- Protective coating:
  - Acrylate is a well-known outgasser, low temperature ratings (max +85C)
  - Outgassing issue can be overcome by using a hermetic protective jacket
  - Polyimide has been avoided by NASA

The second optical fiber requirement: 10 Gbps

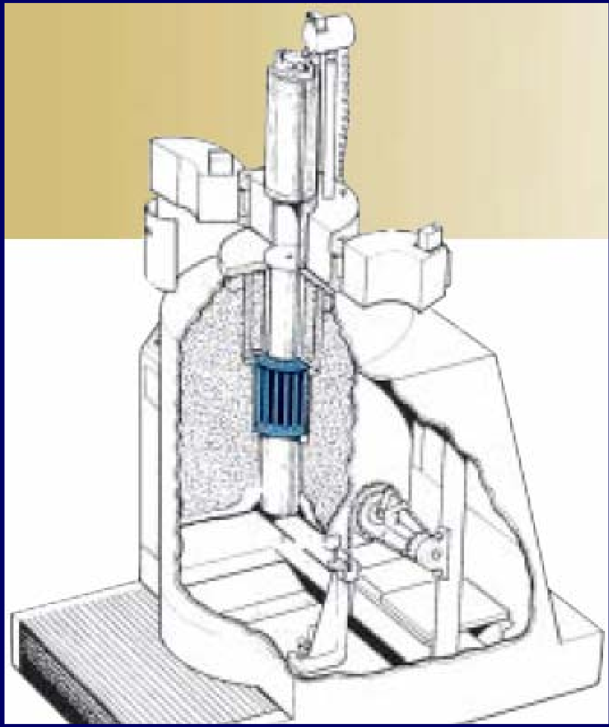
- Wavelength selection (850) due to VCSEL lasers
- Waveguide type
  - The multimode step-index fiber avoided due to bandwidth limitations
  - The singlemode step-index fiber avoided due to low coupling efficiency and stringent alignment tolerances
- The multimode graded-index fibre is the best compromise
  - Good light coupling efficiency with lower alignment tolerances
  - Few Gbps over a short length
- Laser-optimized graded-index multimode fiber
  - New product for next generation high speed systems at 850 nm
  - Designed to keep modes with same average propagation speed
  - Bit rates up to 10 Gbps over 300 to 500 metres
- Currently step-index multimode 100/140 micron fibers are used in space applications

Tested fibers

- **Tested fibers:**
  - **4 Laser-optimized graded-index multimode fibers (LOGIMF)**
    - **Draka MaxCap 300, standard**
    - **Draka MaxCap 300, radhard**
    - **Draka MaxCap 300, radhard-optimized**
    - **Telecom Standard**
  - **Telecom Radhard**
  - **INO Ge-doped graded-index multimode fiber**
- **TIA-455-64:**
  - **Procedure for Measuring Radiation-induced and Attenuation in Optical Fibers and Optical Cables**
  - **It says that a only few microwatts should propagate in fiber during irradiation**

Gamma irradiation test setup

- Tests performed at the Canadian Irradiation Centre
- Gamma radiation from $Cobalt^{60}$
- Average dose rate: 450 Gy/h (45 krad/h)



Fiber spools made of aluminum

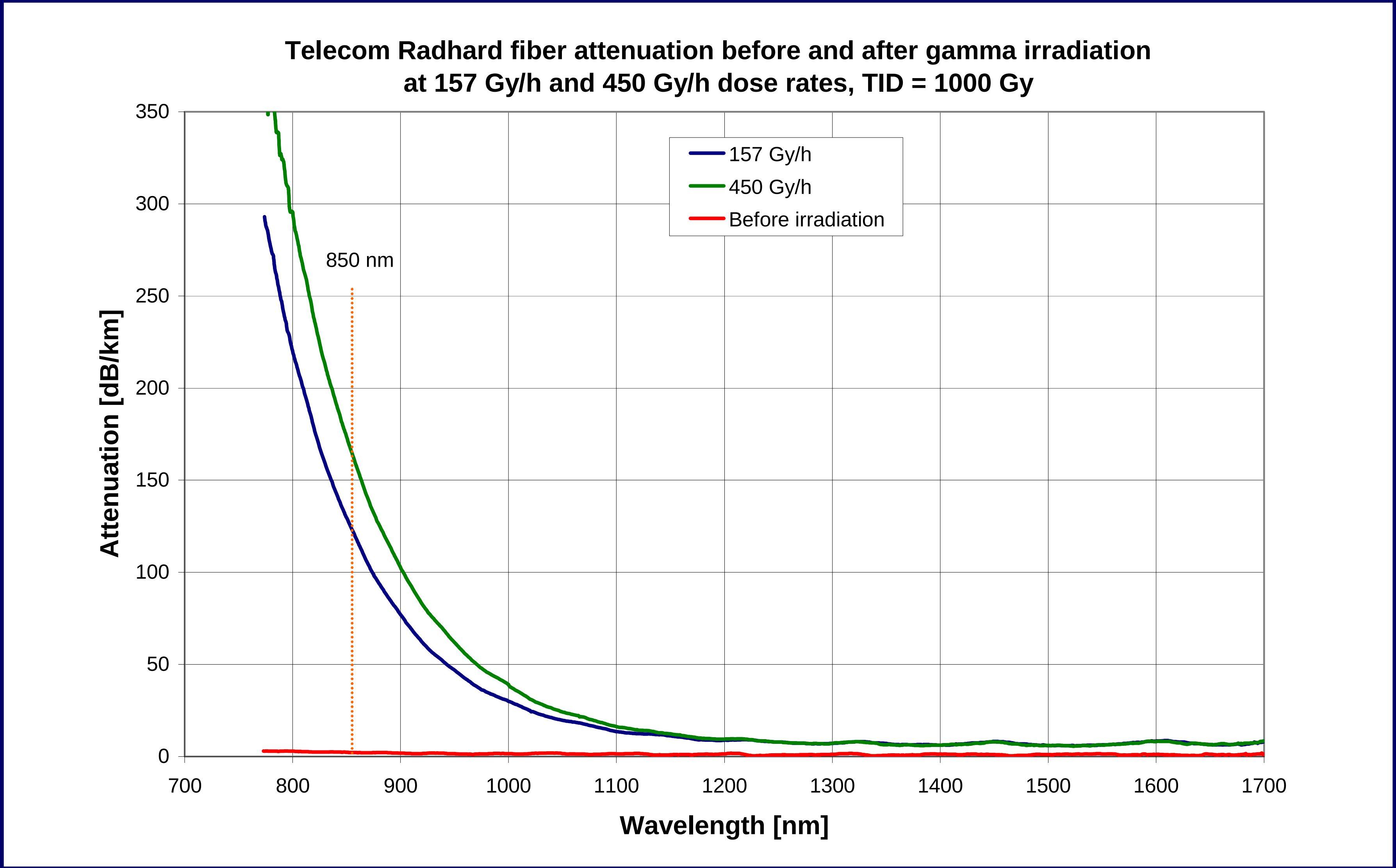
Room temperature spool

Temperature-controlled spool

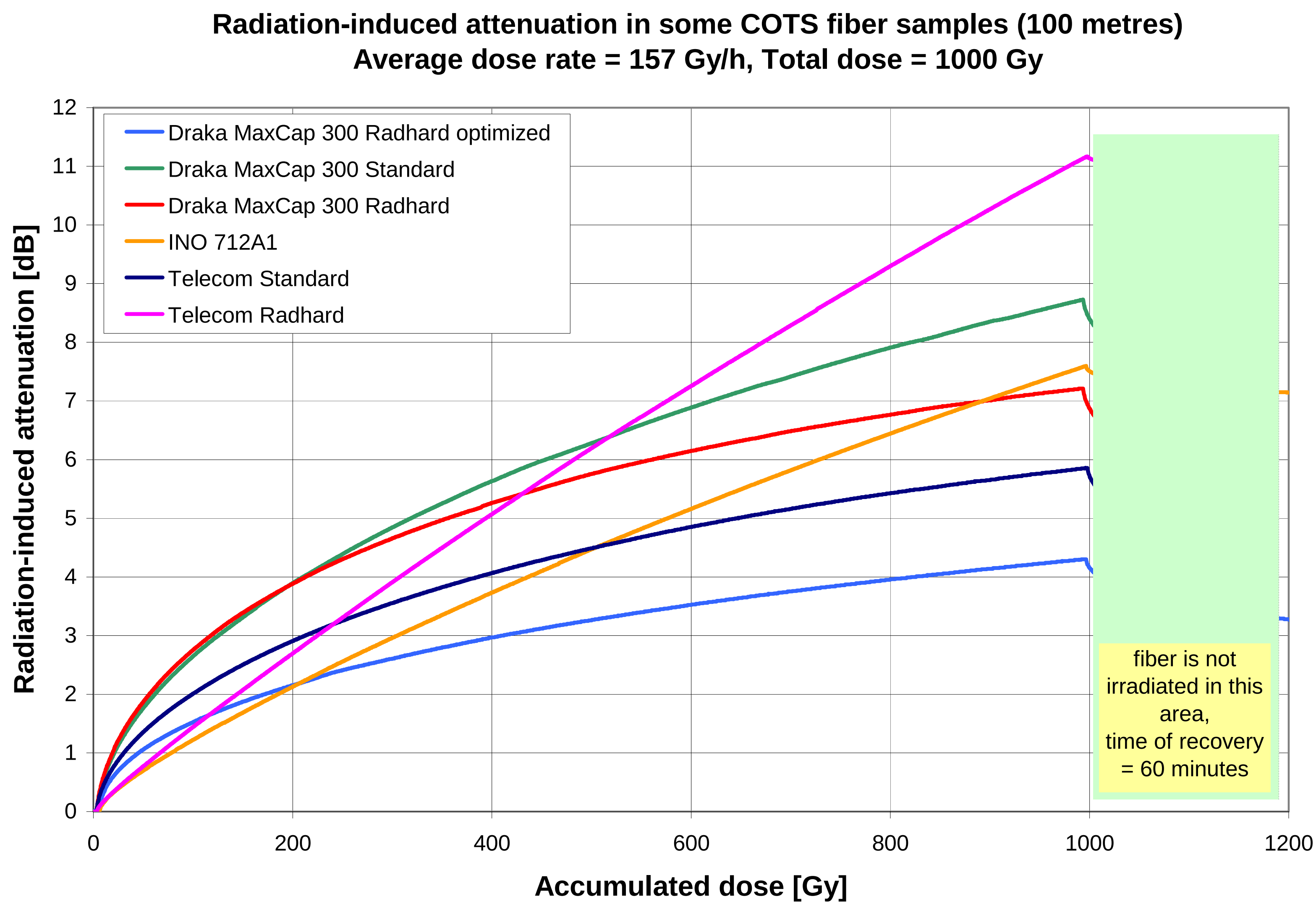
Measurements

- Radiation-induced attenuation (RIA)
  - Two dose rates
  - Room and cold temperatures
- Fits and extrapolations
- Wavelength sensitivity
- Photobleaching test

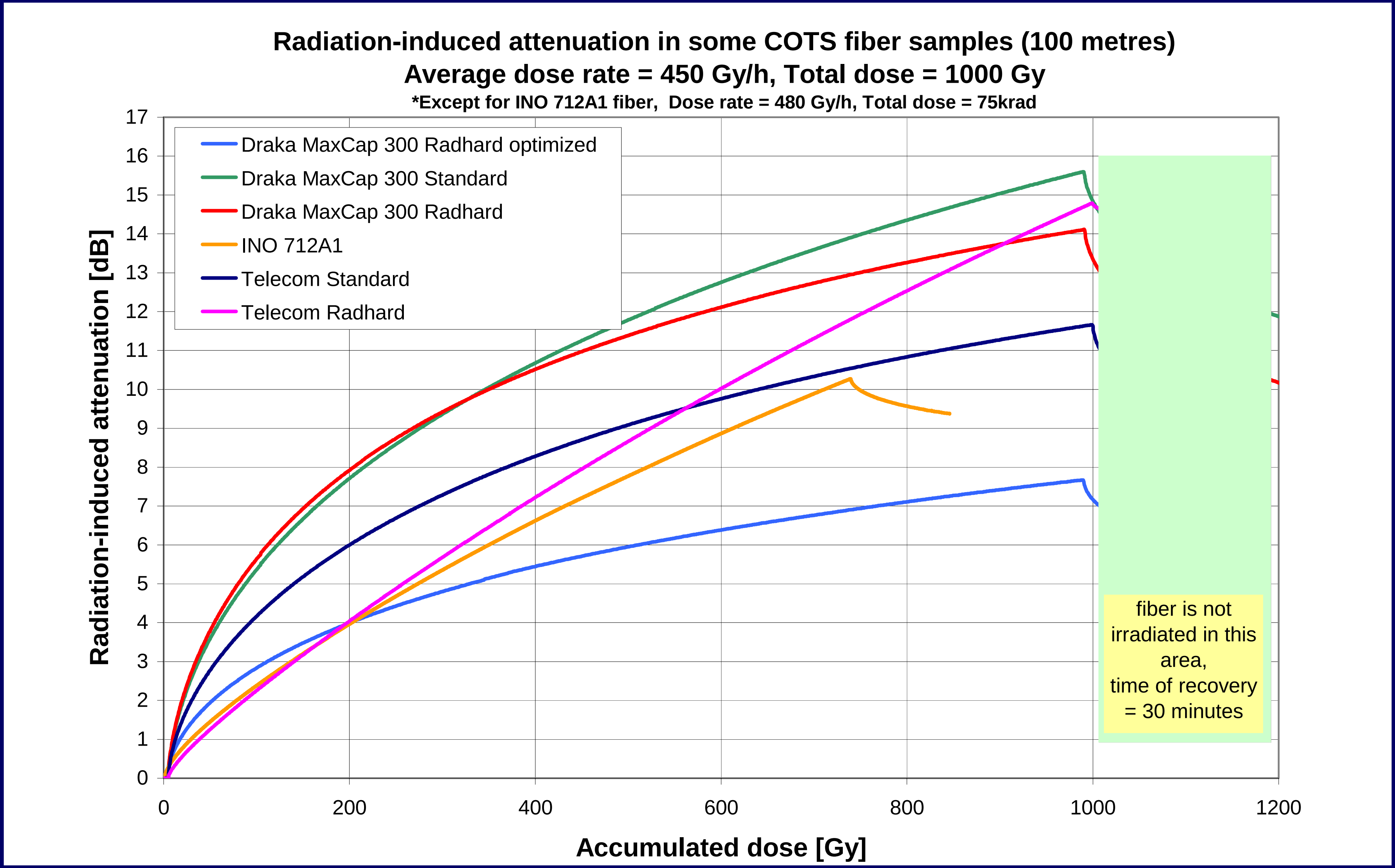
Wavelength sensitivity



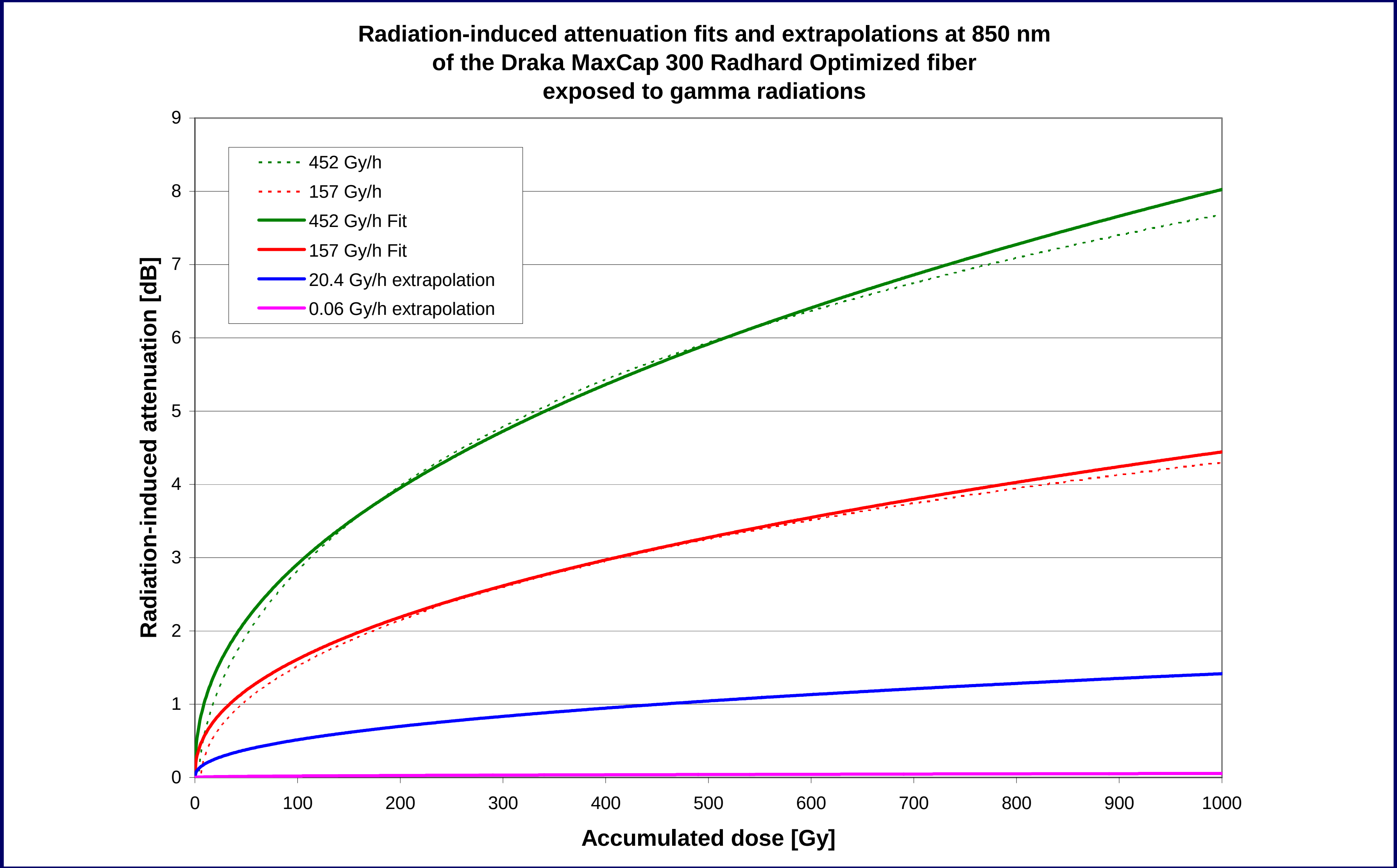
RIA measurements at room temperature (1)



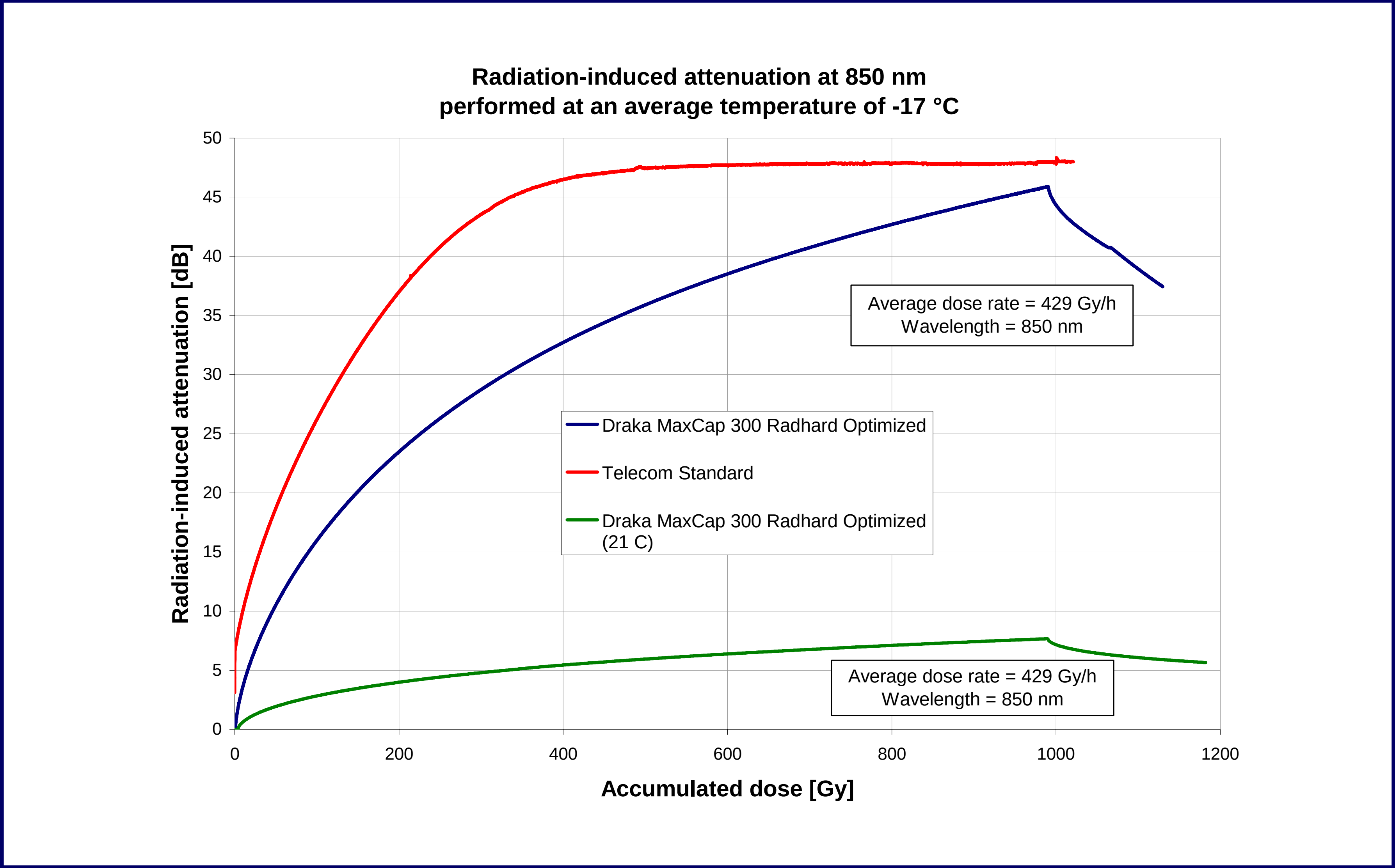
RIA measurements at room temperature (2)



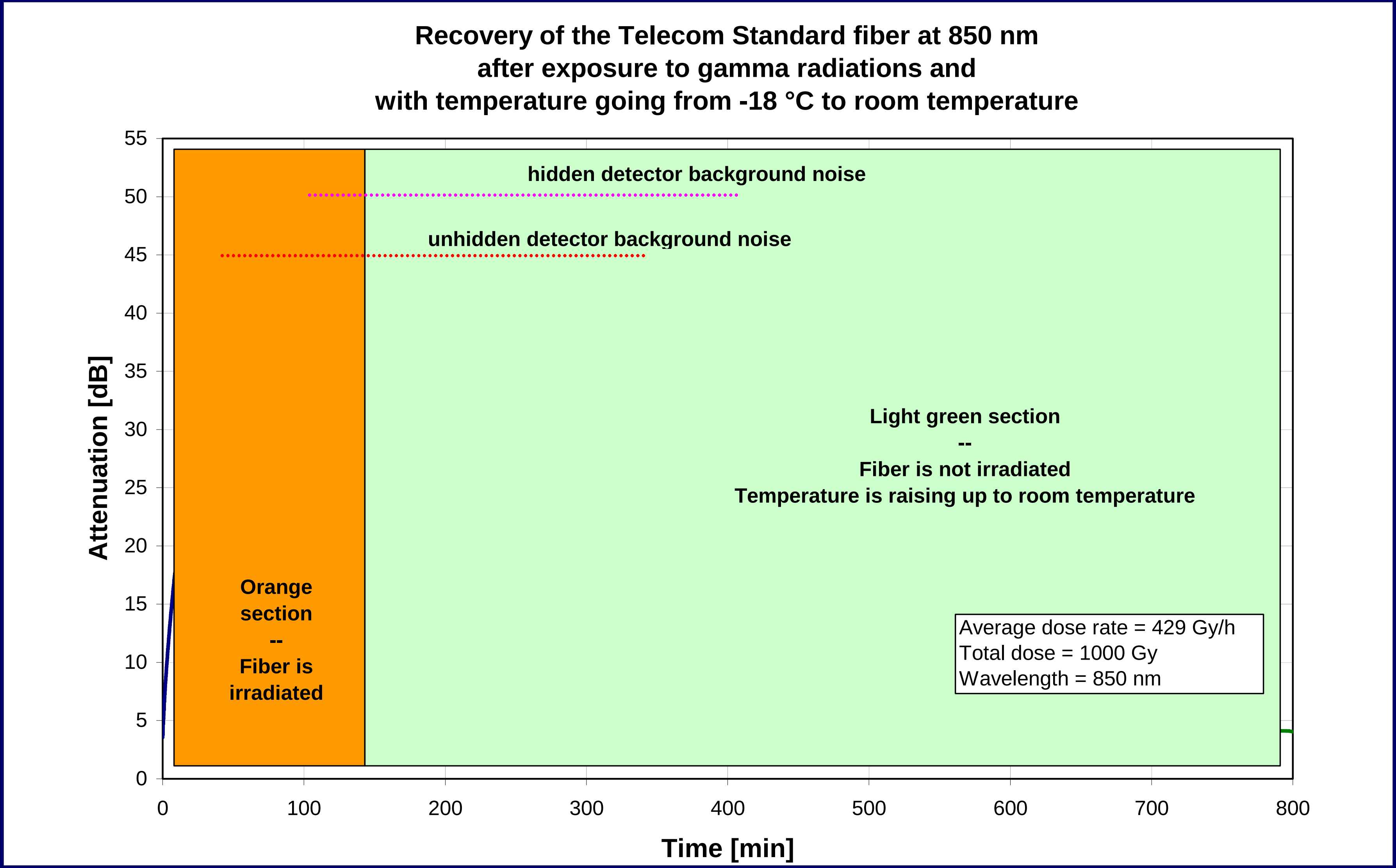
Fits and Extrapolations at room temperature



RIA measurements at cold temperature

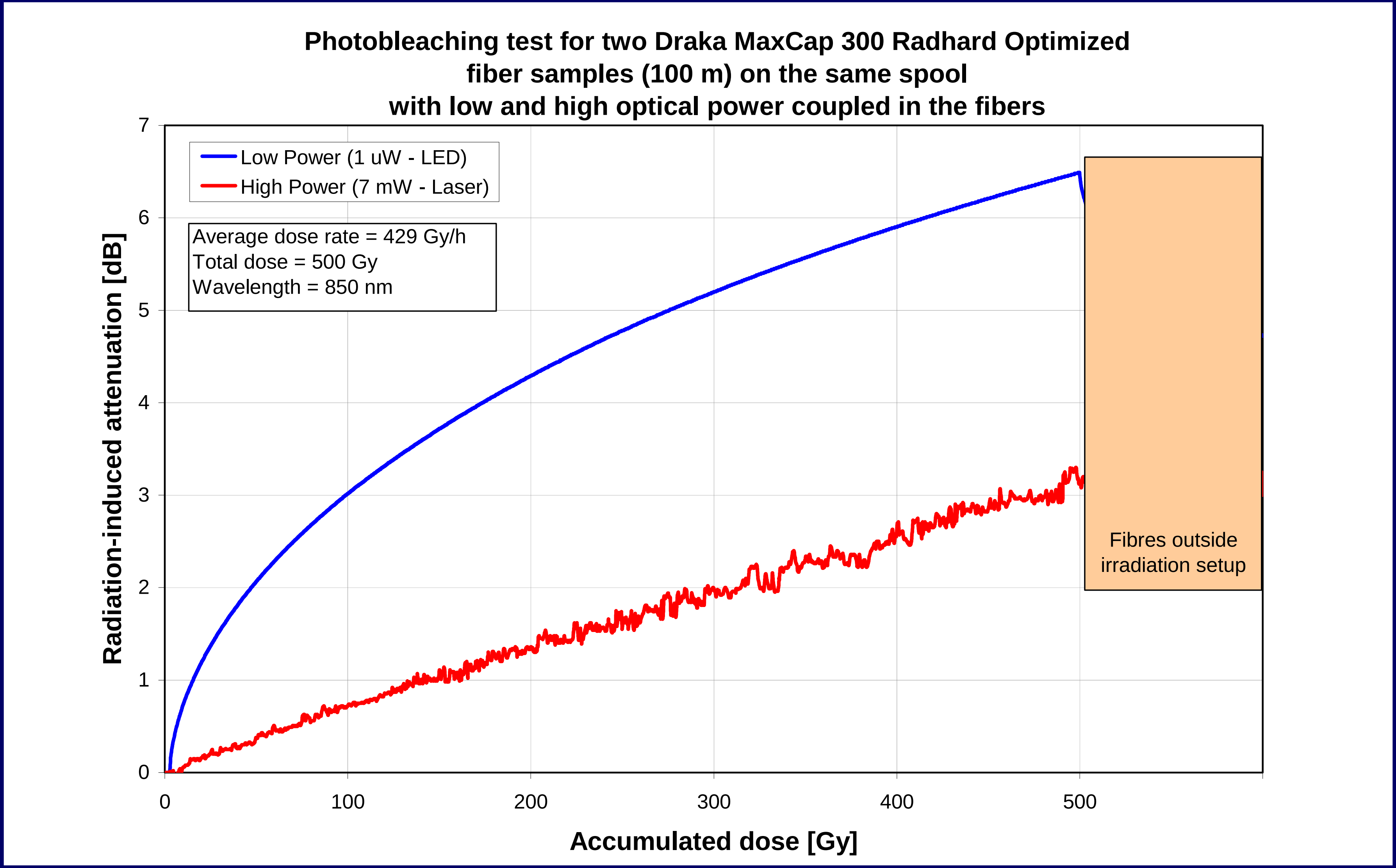


Annealing

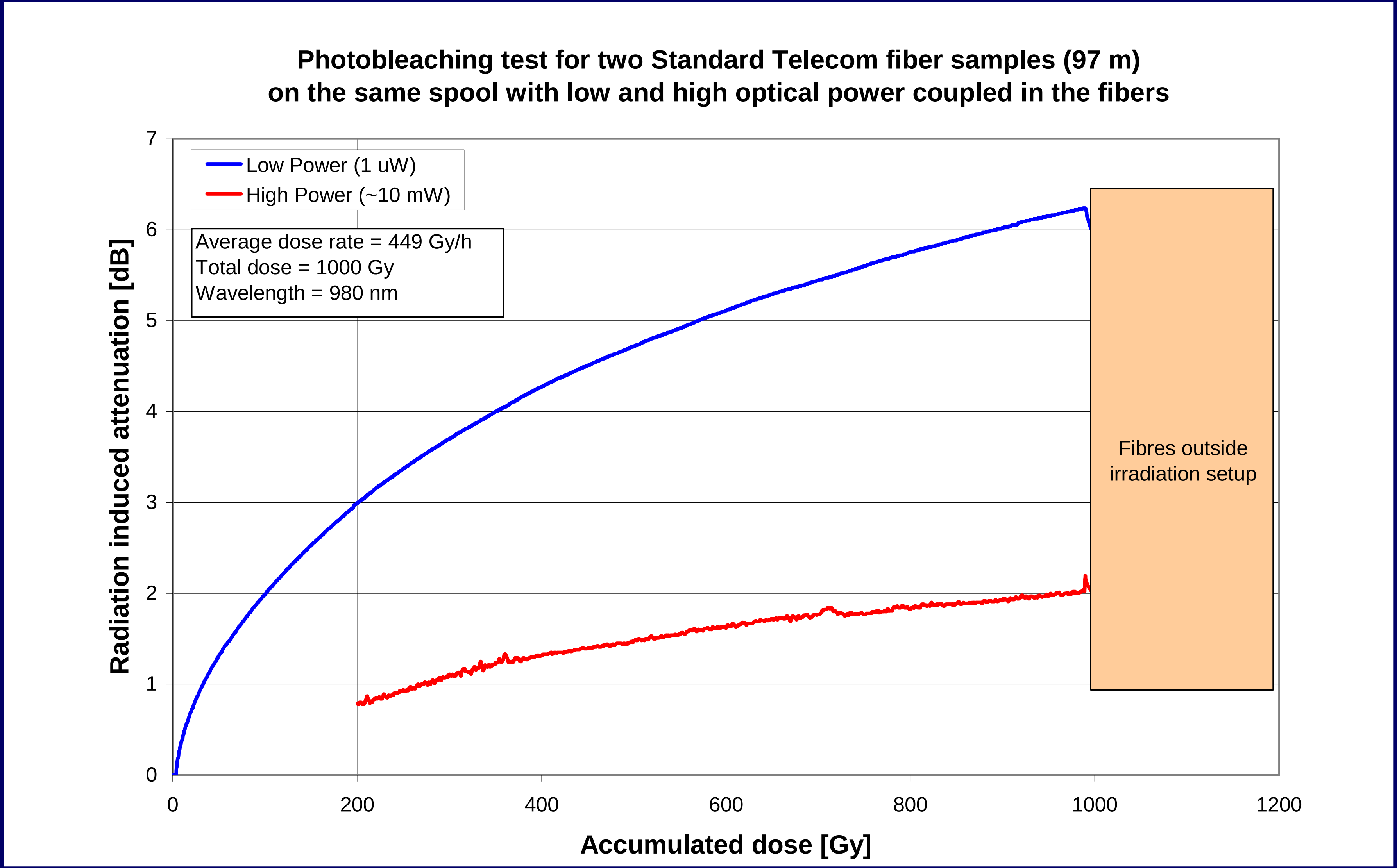


Recovery of the Telecom Standard fiber at 850 nm
after exposure to gamma radiations and
with temperature going from -18 °C to room temperature
hidden detector background noise
unhidden detector background noise
Light green section
--
Fiber is not irradiated
Temperature is raising up to room temperature
Orange section
--
Fiber is irradiated
Average dose rate = 429 Gy/h
Total dose = 1000 Gy
Wavelength = 850 nm
Attenuation [dB]
Time [min]
0
5
10
15
20
25
30
35
40
45
50
55
0
100
200
300
400
500
600
700
800

Photobleaching test (1)



Photobleaching test (2)



Conclusions

- All fibers showed good radiation hardness
- The best performer is the Draka MaxCap 300 radhard-optimized fiber
- Based on extrapolations, RIA losses seems acceptable over a 10-15 years mission lifetime
- As expected, a germanium-doped fiber is much more sensitive to gamma irradiation at low temperatures (may require temperature control of the fiber once in space)