Characterization, Modeling And Storage Of Radiation Induced Attenuation Within Optical Fibers

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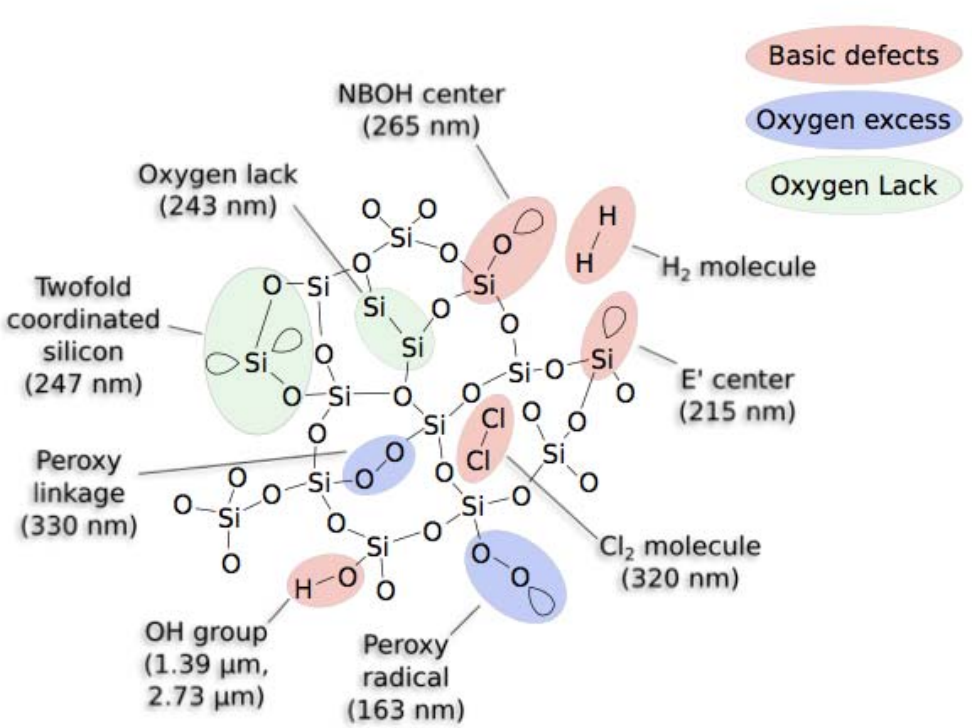
SECOND CNES/ESA FINAL PRESENTATION DAYS

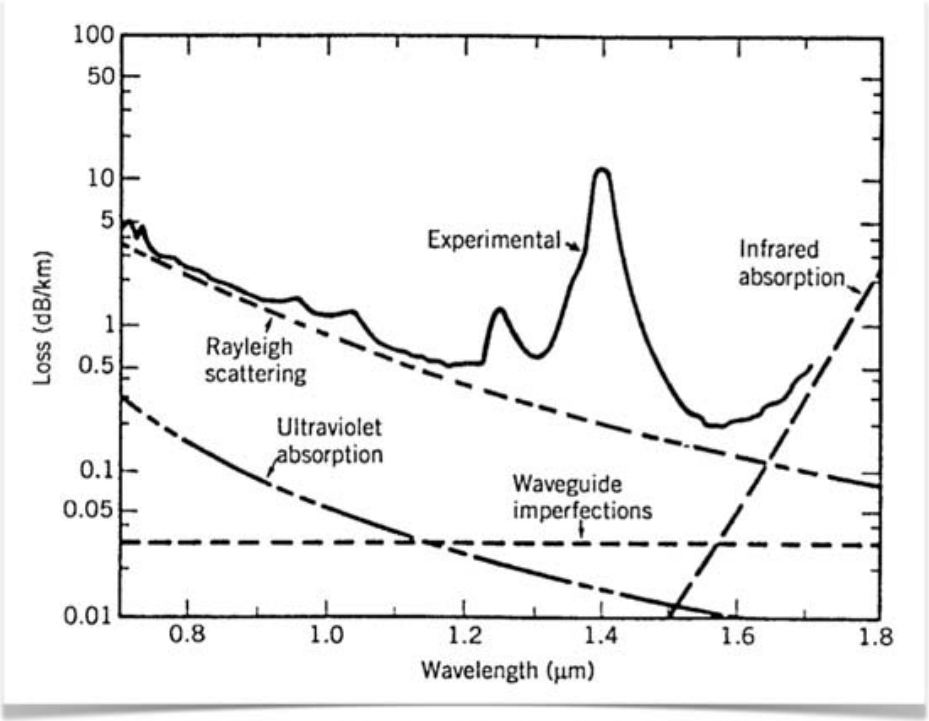
28-29 MARCH 2011

Defects in SiO_2

- Pre-irradiation defects
  - ✓ *Intrinsic Defects* ⟶
  - ✓ *Extrinsic Defects : Si substituted by Ge, P, N, Cl, F, Al*
- Radiation-induced defects
  - ✓ *Electronic and structural modification*



Optical Attenuation in Fibers



Loss spectrum of a single-mode fiber

Before irradiating

- Infrared Absorption
- UV Absorption
- Rayleigh Scattering
- OH^- ion absorption

After irradiating

- UV Absorption ↗

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Finding the Right Component for the Right Use

Problematic

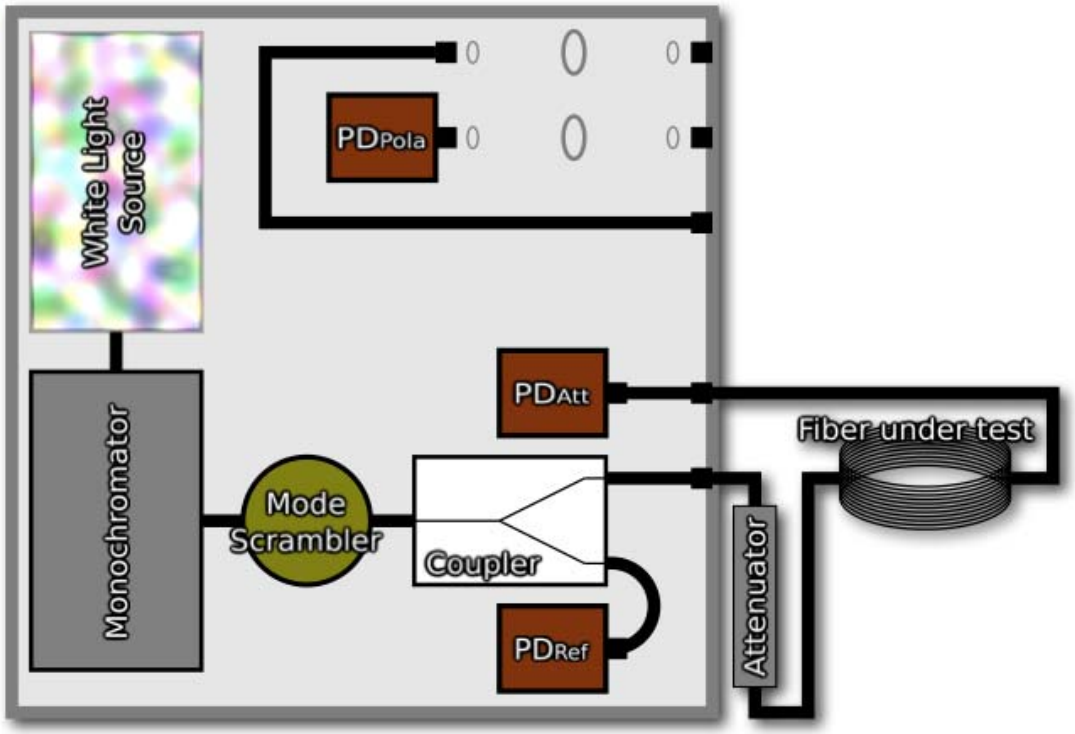
- Different technologies (dopant nature, concentration, profiles) may offer similar ground performance but very different in-flight behaviors.
- Optical fibers : a heterogeneous radiation response.

Contribution

- Development of a test bench.
- Characterize under γ radiation a variety of optical fibers.
- Build predictive models.
- Gather the results in an online database, "RadFiber".

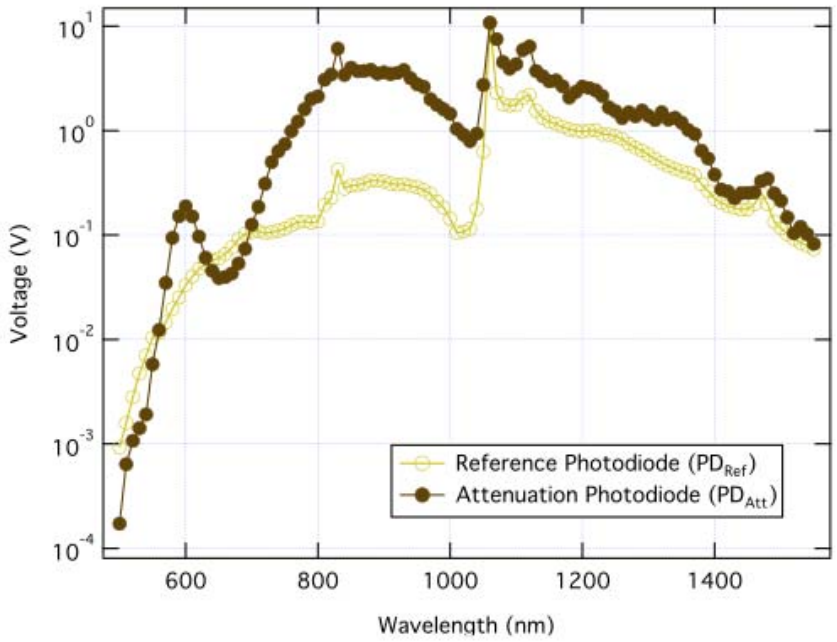
Global Architecture of the Test Bench (attenuation mode)

- **R**adiation-**I**nduced **A**ttenuation (RIA) from 400 nm to 1550 nm.
- Thick black lines : multimode optical patch chords.
- Boxes labeled PD### contain each a "two-color" photodiode.



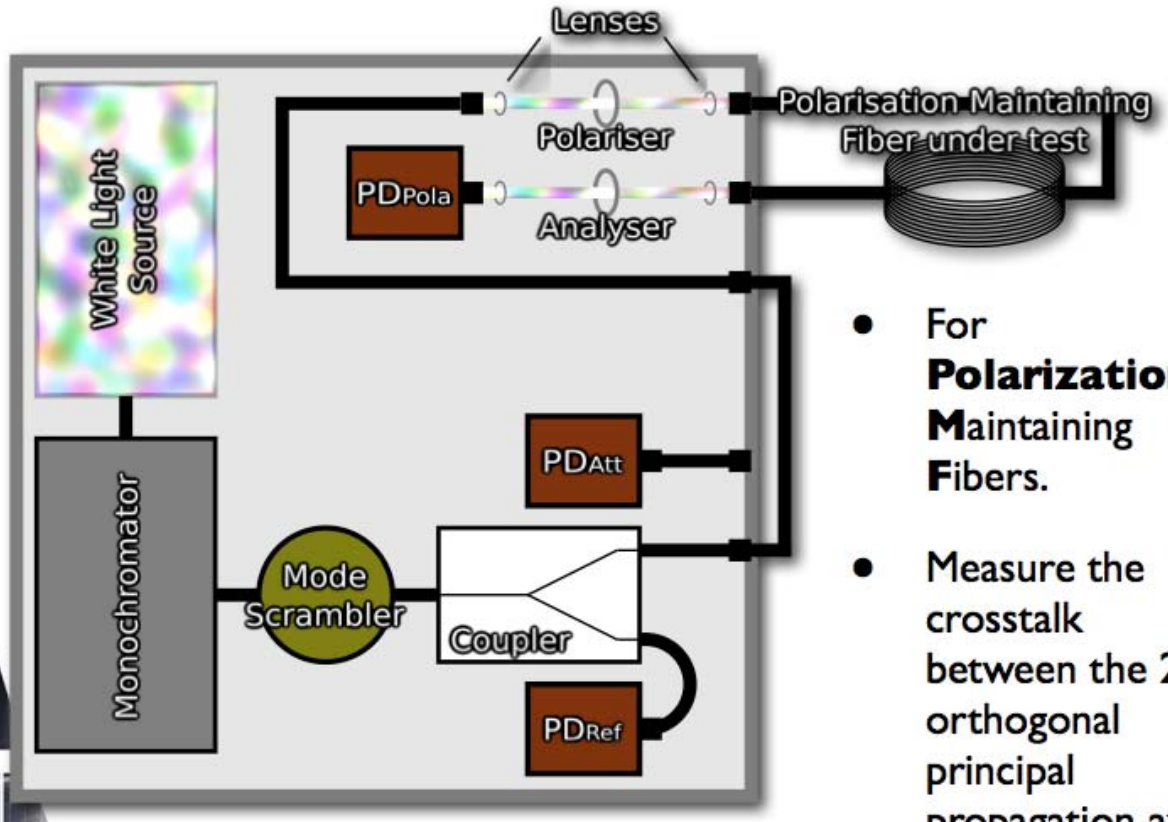
Example of Measurement Showing Two Spectra Obtained from Each Photodiode, PD_{Att} and PD_{Ref}

- Voltage ∝ light flux.
  - PD_{Ref} : before the fiber.
  - PD_{Att} : after the fiber.
- Each point = average over 1000 measurements.

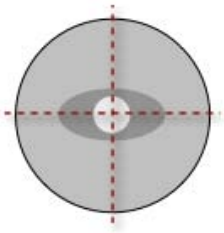


- **R**adiation-**I**nduced **A**ttenuation : $RIA = \frac{(PD_{Att}/PD_{Ref})_{post-irrad}}{(PD_{Att}/PD_{Ref})_{pre-irrad}}$

Global Architecture of the Test Bench (extinction ratio mode)

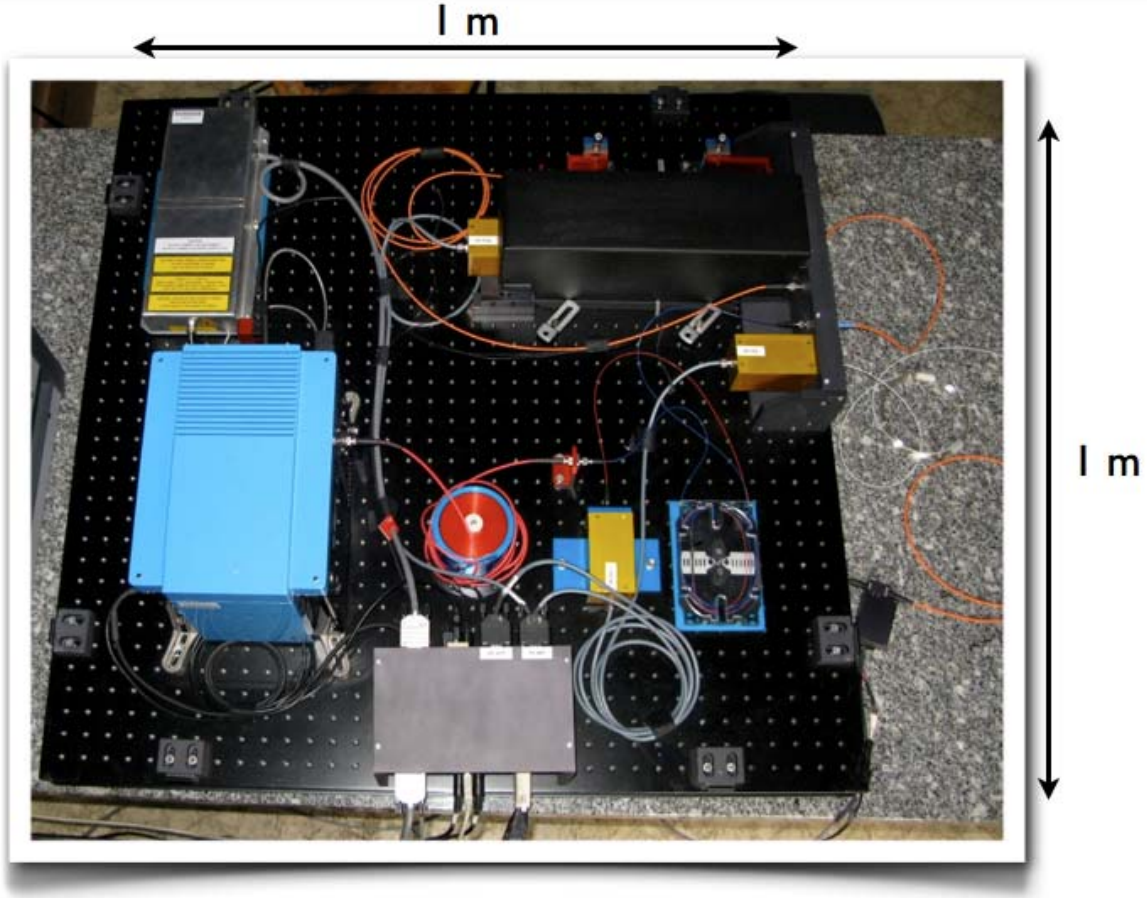


- For **Polarization Maintaining Fibers.**



- Measure the crosstalk between the 2 orthogonal principal propagation axes

Test Bench Close View



Test Bench Overview

- 1 rack case with electronics and power supplies.
- 1 laptop computer.

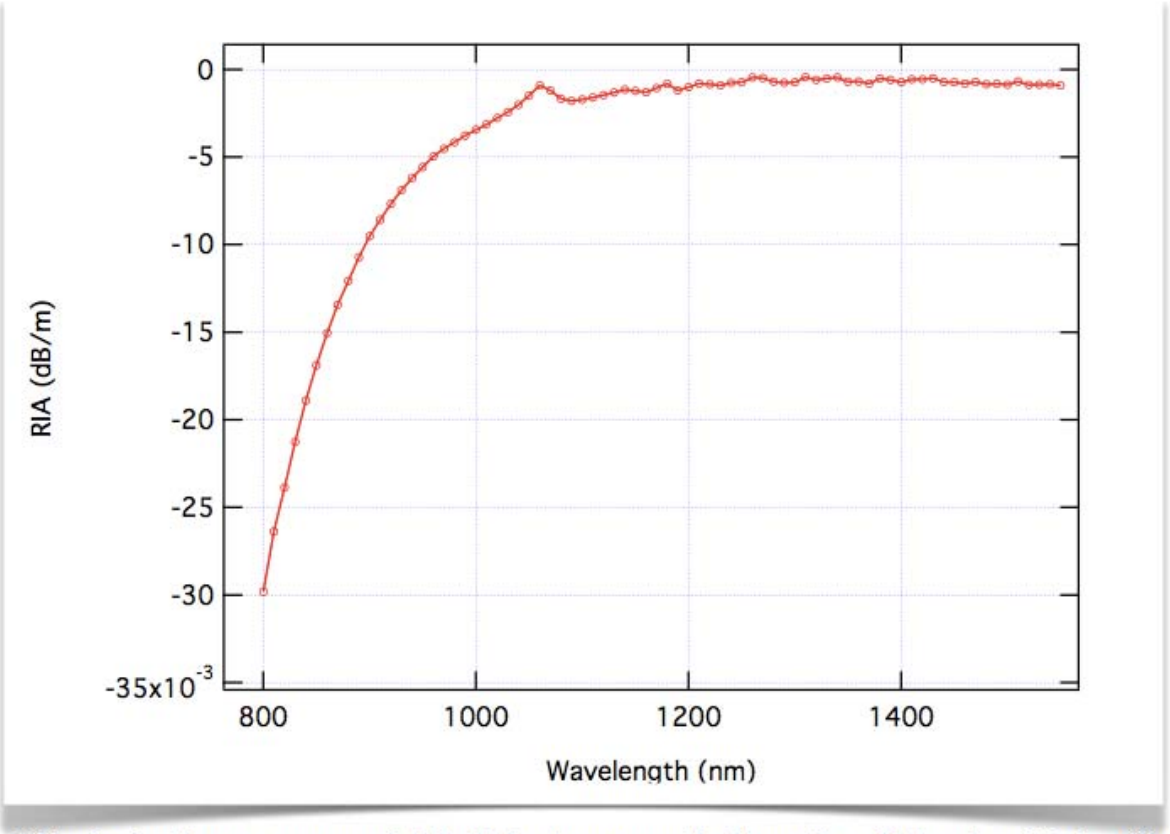
Samples Geometry

- Fibers are winded on unstressed spools.

N°	Designation	Fibre Type	Length (m)	Dose rate (krad/h)	Doses (krad)
1	MO-S1	MOnomode	964.52	4	16, 28, 48
2	MO-S2	MOnomode	971.50	0,3	48
3	MP-S1	Polarization Maintaining	1000.00	4	16, 28, 48
4	MP-S2	Polarization Maintaining	1000.00	0,3	48
5	MU-S1	MUtlimode	196.70	4	16, 28, 48
6	MU-S2	MUtlimode	197.60	0,3	48

- Spool geometry is chosen to minimize dosimetry error.

Radiation-Induced Attenuation of a Monomode Fiber as a Function of Wavelength



RIA obtained on a commercial Rad-Hard monomode fiber after 48 krad at 0.3 krad/h.

RIA Modeling so far

- R.A.B. Devine, Nucl. Inst. & Meth. in Physics Research Section B, Vol. 46, Issues 1-4, 1 Feb. 1990, pp. 261-264, ISSN 0168-583X, DOI: 10.1016/0168-583X(90)90709-4.
→ diffusion based model, distribution of activation energies, stretched exponential fit.

- H. Imai et al., J. of Non-Crystalline Solids, Vol. 179, 4 Nov. 1994, pp. 202-213, ISSN 0022-3093, DOI: 10.1016/0022-3093(94)90698-X.
→ kinetic order 1, dose dependence explained from precursor defects.

- G.M. Williams et al., Proc. of SPIE, 2811, pp. 30-37, 1996.
→ modeling by a sum of saturating exponentials.

- E.H. Friebele et al., Radiation effects in glass, Treatise on material science and technology, Vol. 17, Glass II, edited by M. Tomozawa et R.H. Doremus, Academic Press, 1979.
- P.W. Levy, SPIE Vol. 541, pp. 2-24, 1985.
→ modeling by a sum of saturating exponentials + a linear term.

- M. Kyoto et al., J. of Lightwave Technology, Vol. 10, N°3, pp. 289-294, 1992.
→ modeling by a sum of saturating exponentials + a extra term representing radiation created color centers.

- E.J. Friebele et al., SPIE Vol. 1791, pp. 177-188, 1992.
- J.D.O. McFadden et al., SPIE Vol. 2811, pp. 77-94, 1996.
- P.W. Marshall et al., SPIE Vol. C.R. 50, pp. 189-231, 1994.
→ kinetic order n, "dose rate extrapolation method". Hypothesis : annealing kinetic does not depend on dose rate.

- D.T.H Liu et al., Optics Letters, Vol. 19, N°8, pp. 548-550, 1994.
- R.H. West, Proc. of RADECS 99, pp. 483 - 490.
→ model based on the impulse response of the fiber to a radiation flash (LTI system theory [Linear, Time-Invariant]).

RIA Modeling (1/3)

From *"New model for assessing dose, dose rate, and temperature sensitivity of radiation-induced absorption in glasses"*, J. OF APPLIED PHYSICS 108, 093115 (2010), O. Gilard, M. Caussanel, H. Duval, G. Quadri, and F. Reynaud.

Goal

An accurate model to extrapolate RIA as a function of dose, dose rate and temperature.

Our hypotheses

- RIA is due a single dominant color center : $RIA \propto n$ (color center density)
- Kinetic order β : $\frac{dn}{dt} = generation - recombination(n^{\beta})$
- Recombination kinetic is dispersive (rate processes for which many timescales coexist are called dispersive)

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RIA Modeling (2/3)

$$\frac{dn}{dt} = gN_p\dot{D} - \frac{\alpha}{\tau^\alpha}t^{\alpha-1}n^\beta \quad \text{[eq. 1]}$$

Generation — Recombination

n : Color center density

t : Time

g : Generation coefficient

N_p : Pre-existing defect density

$\dot{D}$: Dose rate

α : Dispersion parameter

τ : Characteristic decay time

β : Kinetic order

Temperature dependence : $\frac{1}{\tau} = \nu e^{-E_a/(k_B T)}$ (Arrhenius law)

ν : frequency factor

E_a : Activation energy

RIA Modeling (3/3)

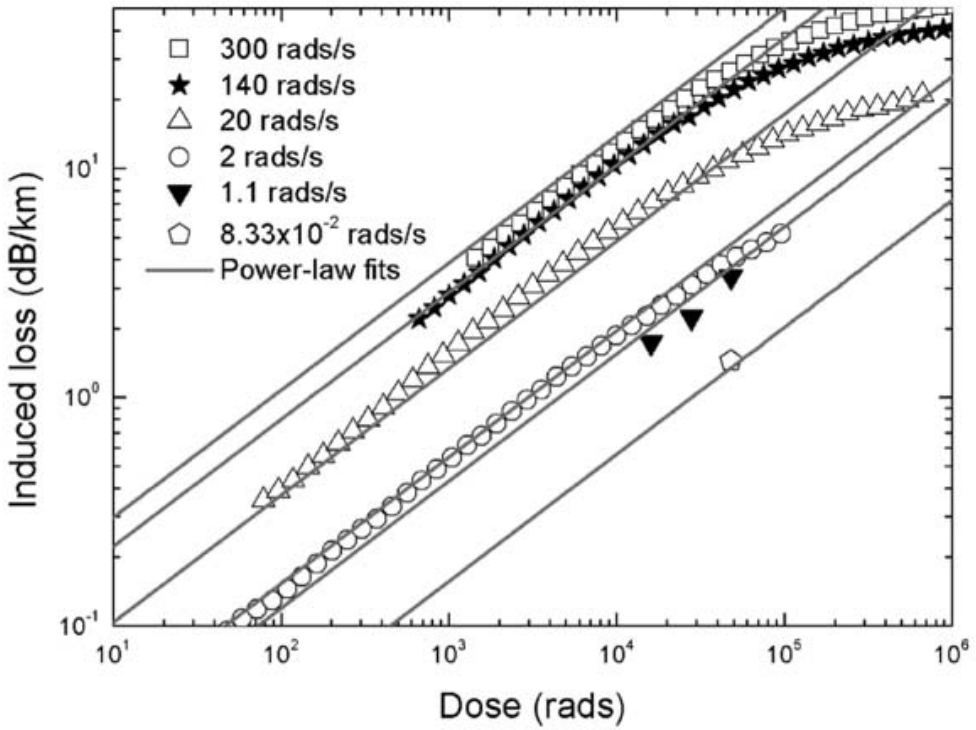
Solving eq. I yields to $RIA = C\, e^{\alpha E_a/(\beta k_B T)}\, \dot{D}^{\alpha/\beta}\, D^{(1-\alpha)/\beta}$ [eq. 2]

Determined by the experiments.
- D : Dose
- $\dot{D}$: Dose rate
- T : Temperature

Determined by the data fitting.
- E_a : Activation Energy
- α : Dispersion Parameter
- β : Kinetic order
- C : Parameter

Using the model (1/2)

Measurements are fitted to obtained numerical values for model parameters.



E_a = 2.8 eV

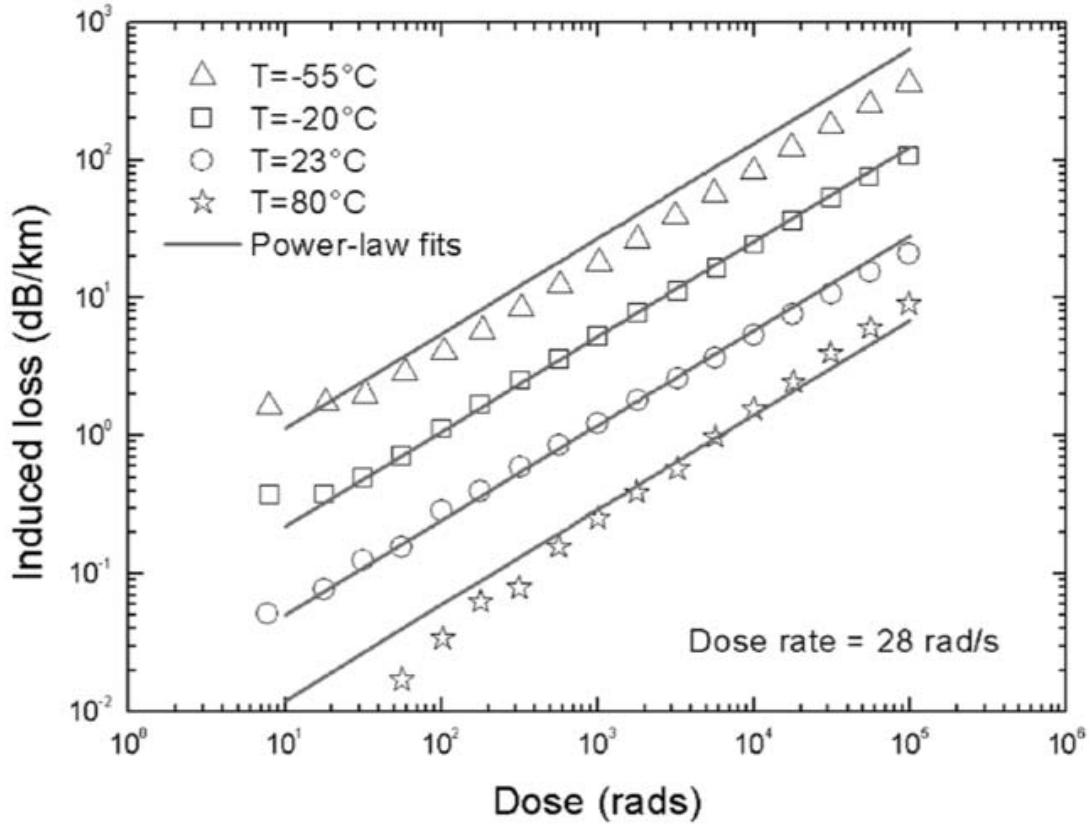
α = 0.1

β = 1.3

C = 1.3×10^{-6}

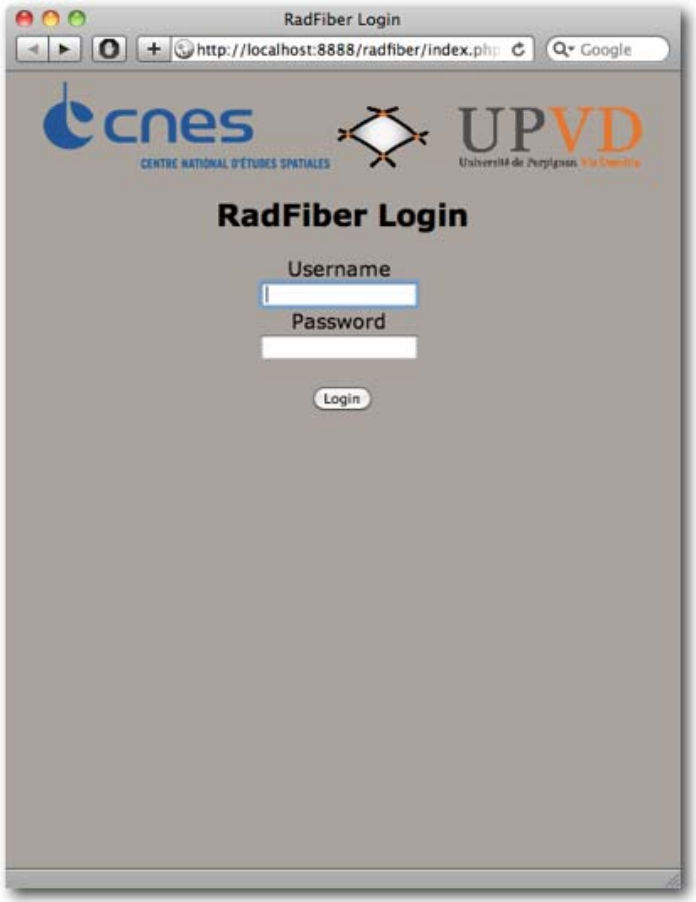
Part of data is from "T. Wijnands et al., IEEE Trans. Nucl. Sci. 55, 2216 (2008)".

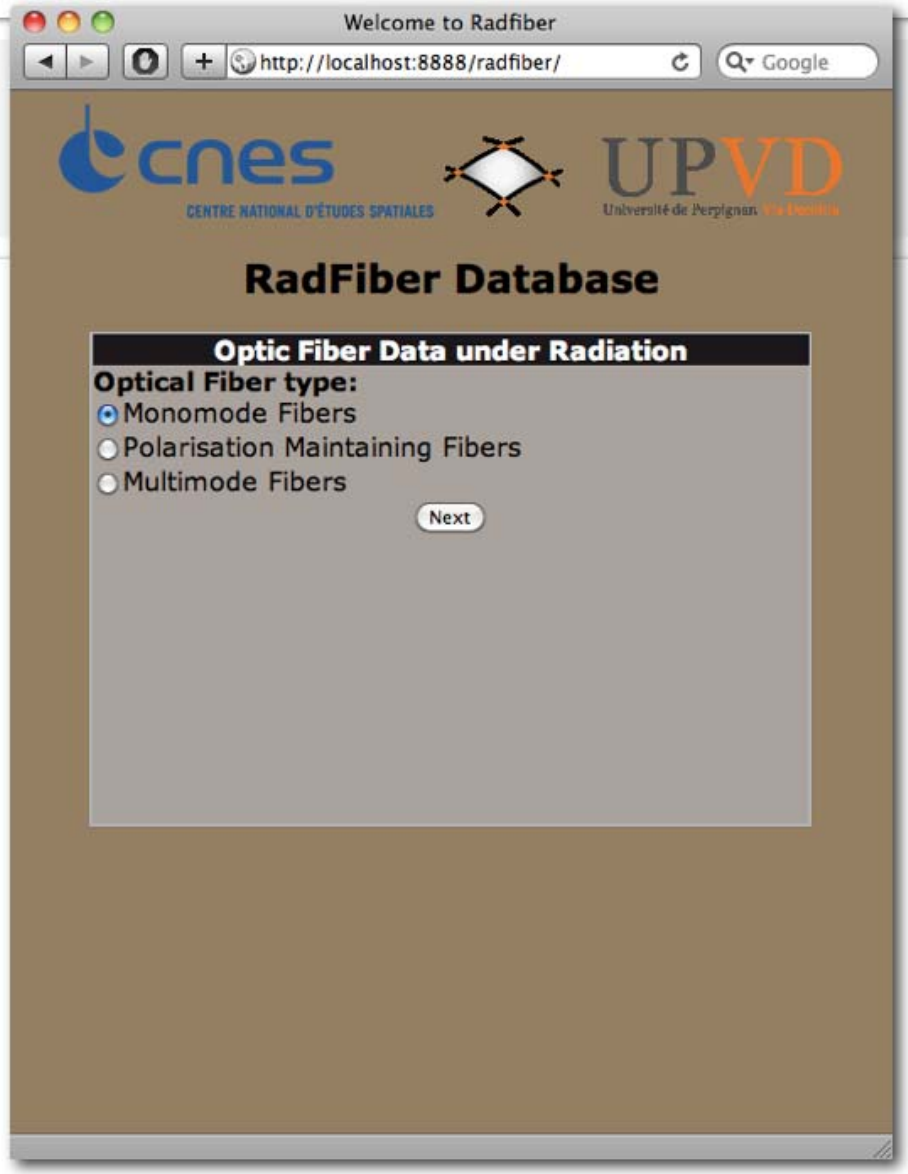
Using the model (2/2)



Data are from "D. L. Griscom et al., Phys. Rev. Lett. 71, 1019 (1993)".

The Online Database : "RadFiber"




Welcome to Radfiber
http://localhost:8888/radfiber/
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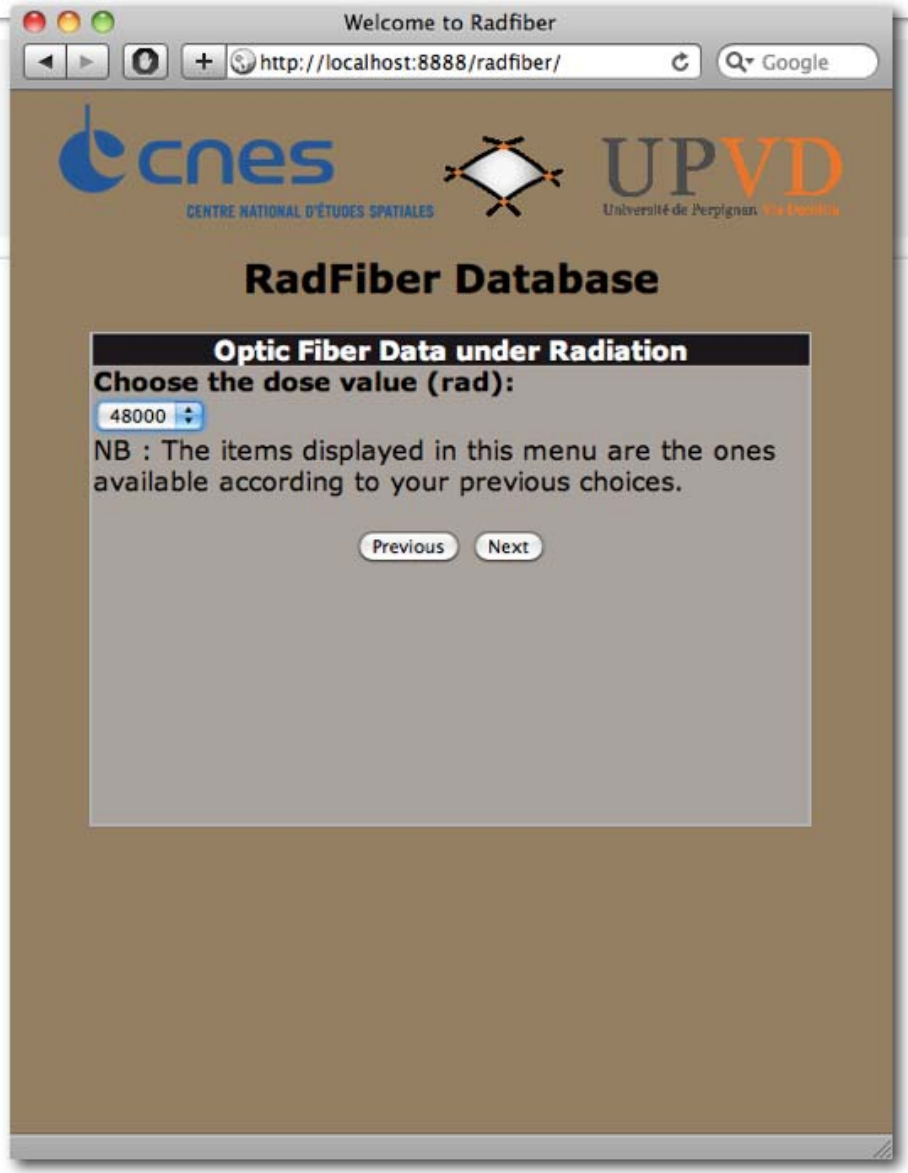
CENTRE NATIONAL D'ÉTUDES SPATIALES
UPVD
Université de Perpignan Via Domitia
RadFiber Database
Optic Fiber Data under Radiation
Optical Fiber type:
Monomode Fibers
Polarisation Maintaining Fibers
Multimode Fibers
Next


Welcome to Radfiber
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RadFiber Database
Optic Fiber Data under Radiation
Choose the dose value (rad):
48000
NB : The items displayed in this menu are the ones available according to your previous choices.
Previous
Next

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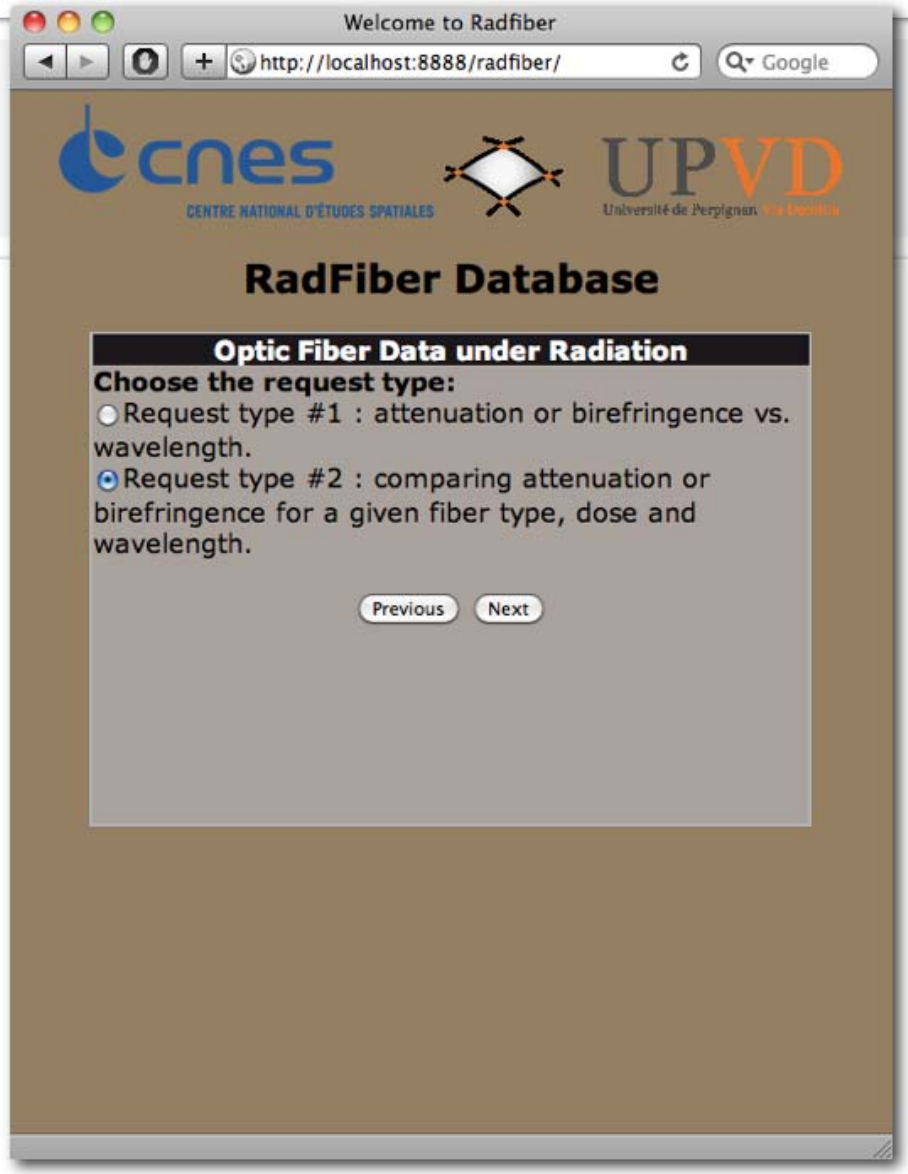

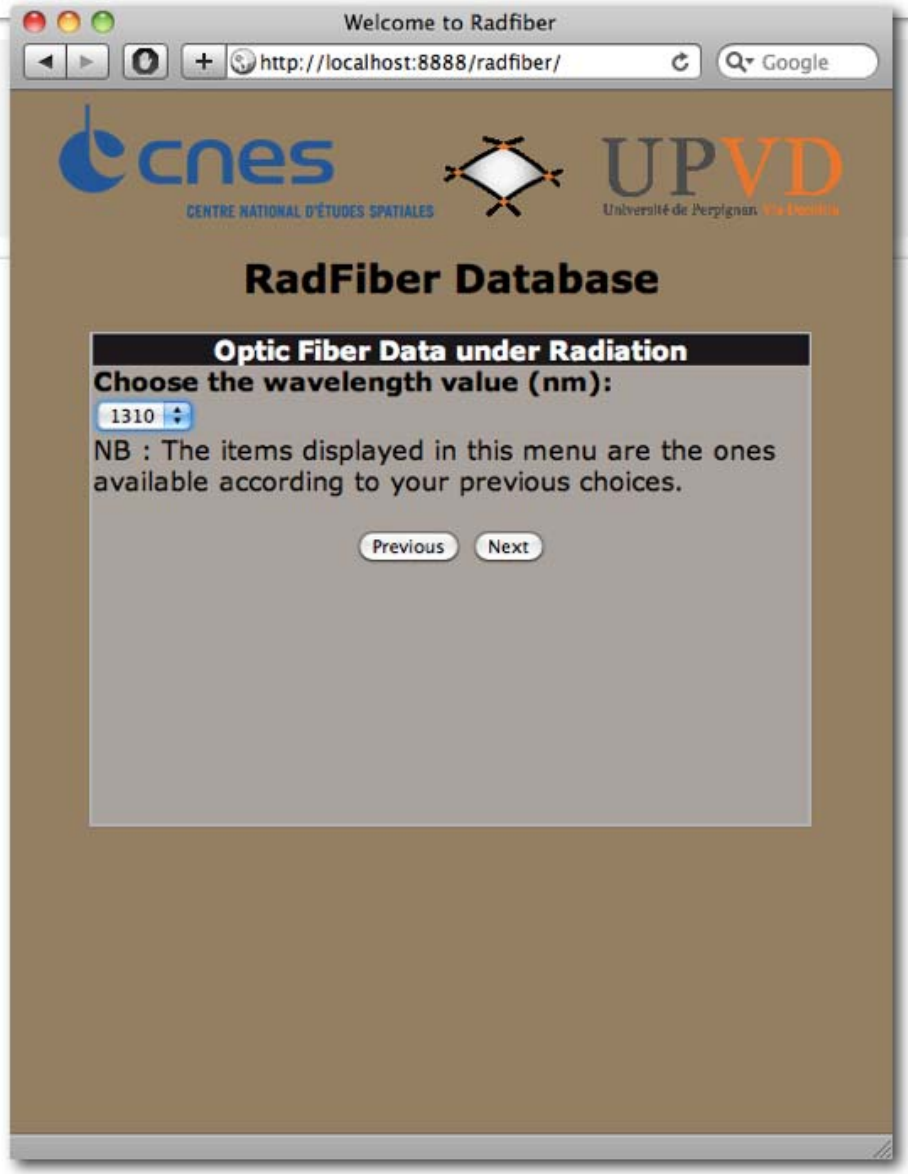
Welcome to Radfiber
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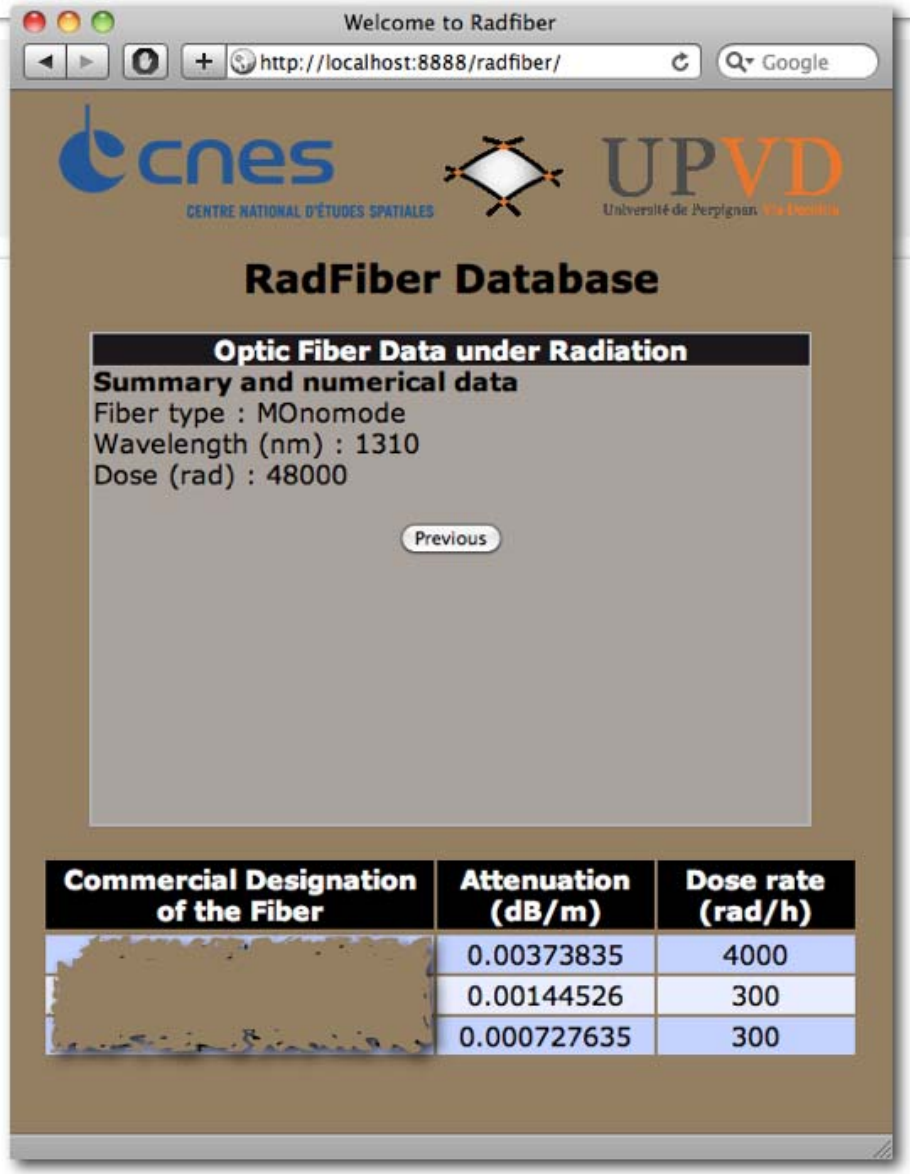
RadFiber Database
Optic Fiber Data under Radiation
Choose the wavelength value (nm):
1310
NB : The items displayed in this menu are the ones available according to your previous choices.
Previous
Next


Welcome to Radfiber
http://localhost:8888/radfiber/
Google
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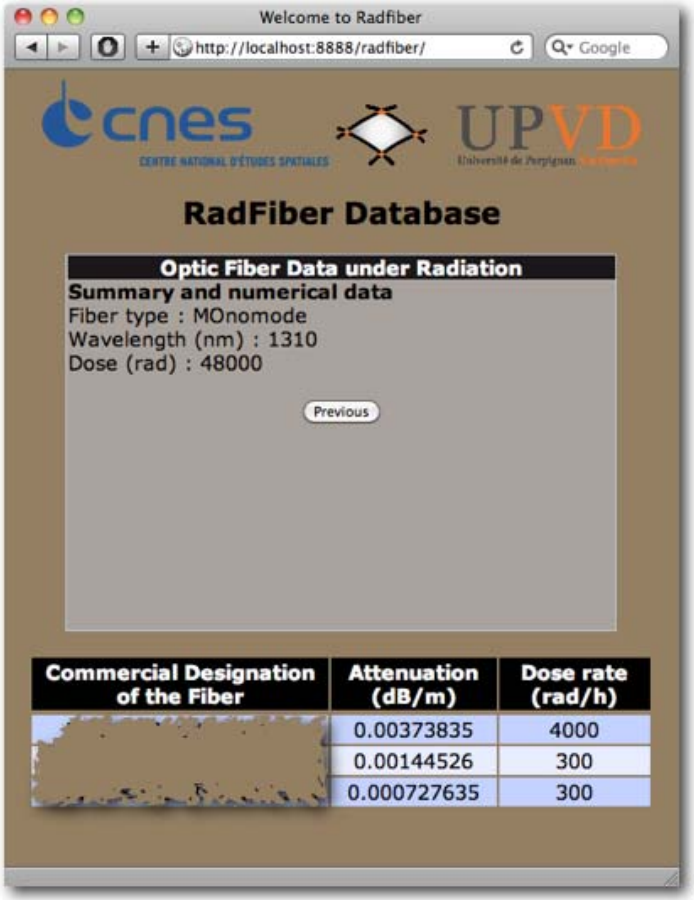
Université de Perpignan Via Domitia
RadFiber Database
Optic Fiber Data under Radiation
Summary and numerical data
Fiber type : MOnomode
Wavelength (nm) : 1310
Dose (rad) : 48000
Previous
Commercial Designation of the Fiber
Attenuation (dB/m)
Dose rate (rad/h)
0.00373835
4000
0.00144526
300
0.000727635
300

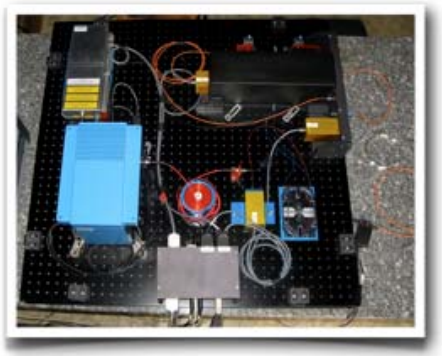
The Online Database, "RadFiber", …

- … hosts the experimental results.
- … allows to extract specific data according to user choices.
- … permits to compare the performances of numerous fibers in order to select the right one for a given space mission.
- … will include a dose/dose rate/ temperature extrapolation tool based on RIA modeling.



Conclusion

- Portable test bench to characterize optical fibers under radiations.
- Measurements serve as a basis to build a predictive model.
- Results are gathered in an online database which helps in selecting the right fiber according to various parameters.



Perspectives

- Make the database bigger.
- Open to collaborations with manufacturers, industries and agencies.
- Carry out irradiations at various temperatures to test the model.