Gamma Radiation Effects in Yb-Doped Optical Fiber

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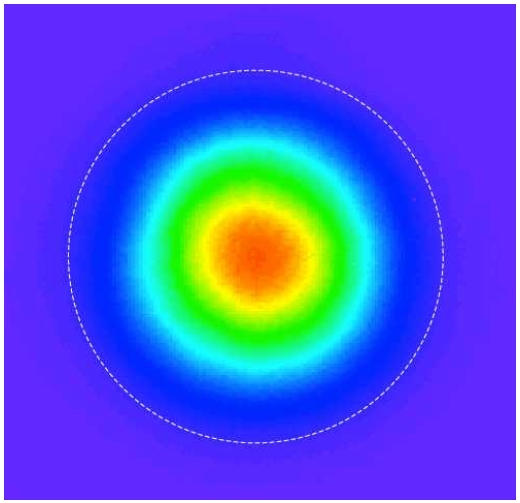
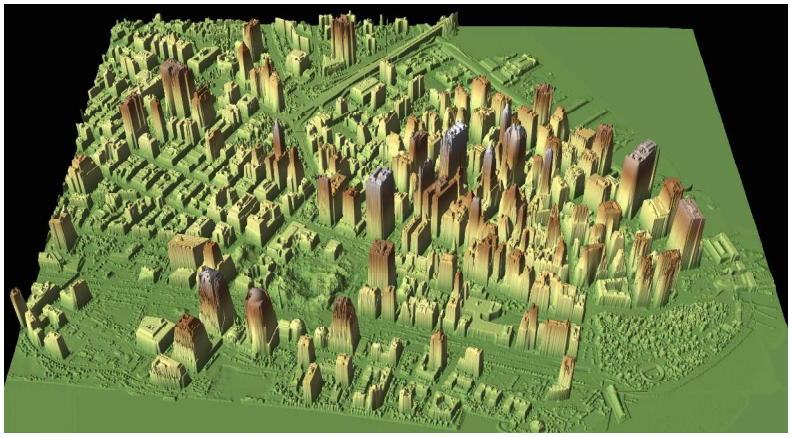
Advantages of Fiber Lasers for Space-Based Applications

- **High efficiency**
  - low power consumption, low waste-heat generation
  - Sandia researchers have demonstrated up to 40% electrical-to-optical conversion with a Yb-doped fiber amplifier.
- **Diffraction-limited beam quality**
  - minimum divergence, smallest spot size
  - reduced speckle
- **High reliability**
  - fiber-coupled components
  - sealed, alignment-free optical system



Applications

- **Remote sensing**
  - physical sensing (altimetry, ranging, 3-D Lidar)
  - chemical sensing
- **High-bandwidth communications**



- **Fiber-laser technologies and systems must meet the stringent requirements of these applications.**

Space Radiation Environment

Radiation in near-Earth space comes from 3 sources:

- **Galactic Cosmic Rays (GCR)**
  - protons (87%), alpha particles, electrons and positrons, heavy ions, low energy, partially ionized particles, gamma rays
- **Radiation belt particles**
  - trapped electrons (low energies, < 5 MeV at 1.4 RE, and high energies, <7 MeV between 2.8 and 12 RE)
  - trapped protons 150-250 MeV farther out, except for the South Atlantic Anomaly (SAA) near the coast of Brazil
- **Solar radiation: background and events (flares and coronal mass ejections)**
  - low energy protons and electrons, gamma rays, high energy protons

Of particular interest to optical materials performance is the effect of gamma radiation on transmission. Anticipated exposure = 1.5 – 3 krad (Si)/5 years (low-Earth orbit).

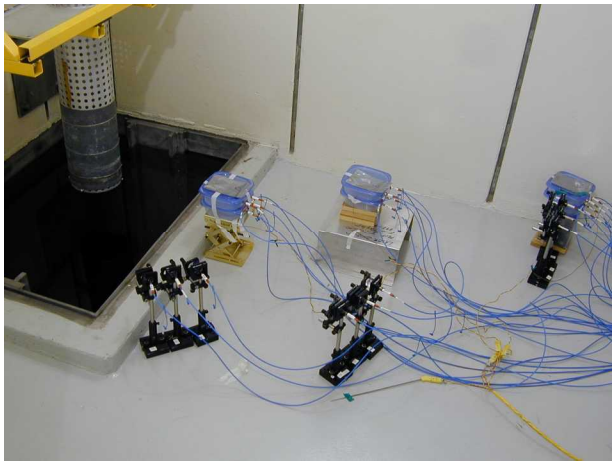
Typical Radiation in Low Earth Orbits

- **Low Earth Orbit (LEO): 300-500 km at 30 to 90^{o} inclination**
- **At low inclinations GCR is negligible due to geomagnetic shielding and electron bremsstrahlung is negligible if the Al shield is more than 1 cm thick.**
- **Gamma photons are the main concern in LEO at low inclinations**
  - But crossing the SAA anomaly exposes the craft to trapped protons and electrons.
  - As the orbital diameter increases, the trapped proton flux increases and the trapped electron flux decreases.
- **Solar flares contribute increased gamma flux and high particle flux** (At low inclinations geomagnetic shielding reduces the charged particle flux, but at 60^{o} inclination the proton flux increases to 40 times the annual dose).

Optical Fiber Radiation Testing

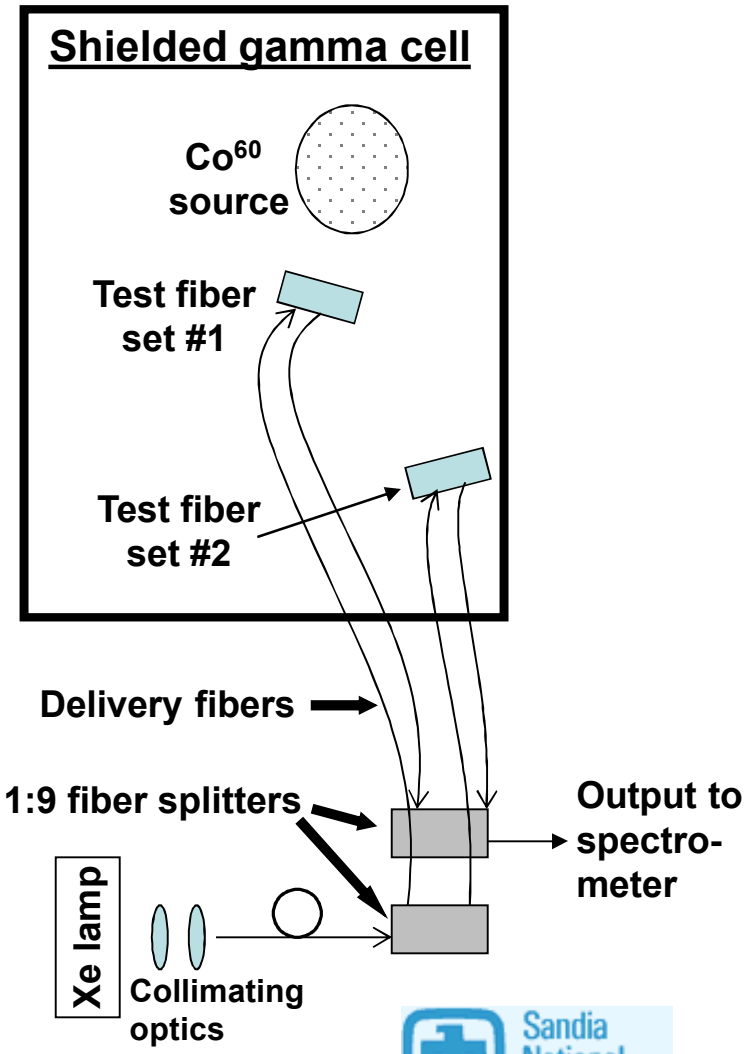
- Optical materials are known to **photodarken in the presence of energetic photons** (hard x-ray, **gamma** radiation).
- **Photodarkening, defined as radiation-induced optical absorption, results in degradation of the transmission of optical signals by optical materials. ie: degradation of device performance.**

Sandia National Laboratories Gamma Irradiation Facility (GIF):
Co^{60} array capable of delivering constant flux of gamma radiation from 100 rad/min to 4.8 krad/min. Rate is dependent upon position of the sample within the test chamber.



Experimental Procedures

- Test fibers located in gamma test chamber for radiation exposure.
- Broadband optical radiation from xenon arc lamp, located outside the test chamber, is coupled into a set of standard SiO_2 delivery fibers.
- Delivery fibers enter test chamber through access ports and couple light into the test fibers located inside the gamma test chamber.
- Transmission spectrum of each test fiber monitored at 1 min. intervals throughout ~7 hour gamma exposure.

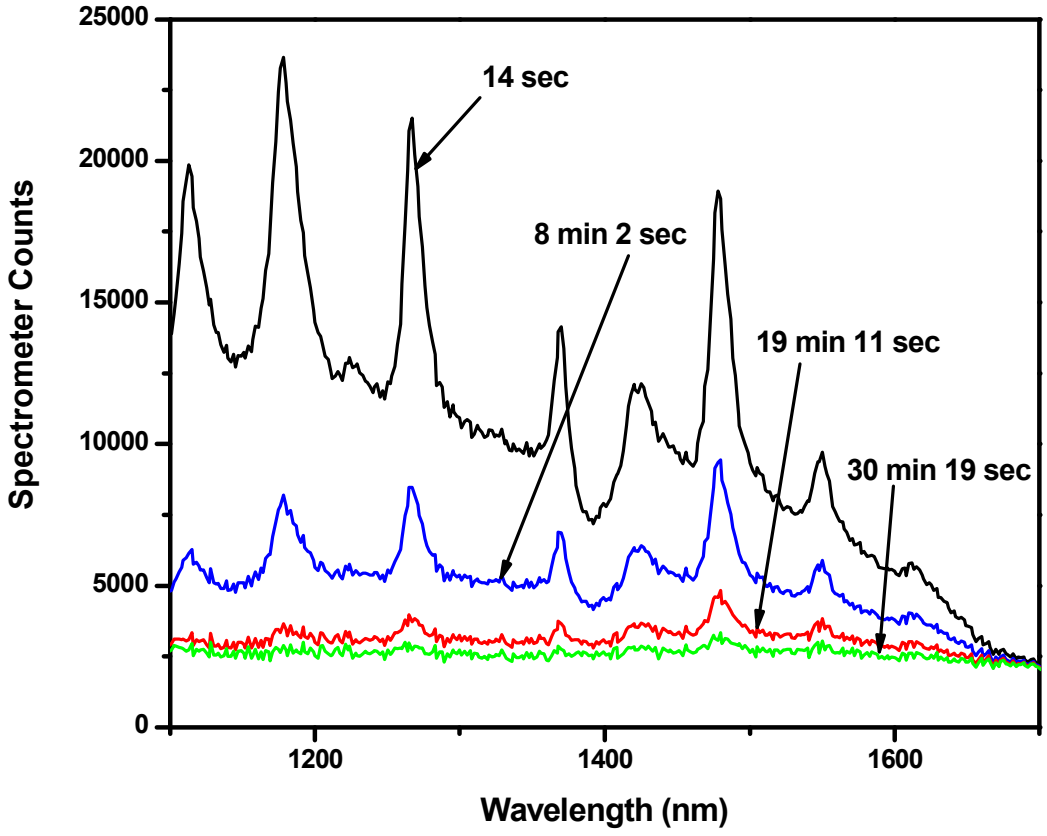


Experimental Procedures II

- Fiber samples consisted of ~3 meter long Yb-doped aluminosilicate Liekki fibers of varying core/clad ratio and composition.
- Pigtails (SMF-28, HI-1060) were utilized to couple “white” light into the core of double-clad Yb-doped fibers.
- Broadband wavelength spectra were acquired on all doped fiber samples as a function of total accumulated radiation dose. In addition, spectra were obtained on individual samples of pigtails and delivery fibers throughout the radiation exposures so that losses in those materials could be accounted for independently.
- All transmittance data are reported for transmission loss experienced per 1 meter of fiber length.

Raw Spectral Data

- Data plot of spectrometer counts vs wavelength of a Yb1200-4/125 fiber before data processing.
- No removal of radiation effects in pigtails or delivery fibers has occurred.
- The lamp spectrum and an offset from the horizontal axis (corresponding to the instrument noise floor) are clearly visible.

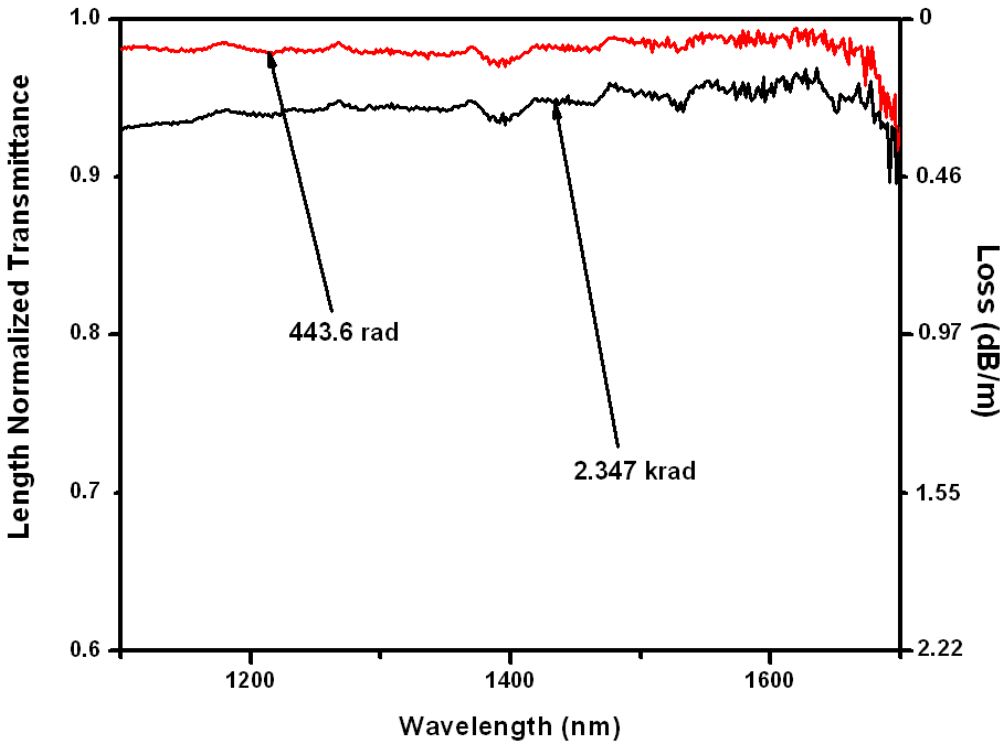


- Dose rate = 40.1 rad/s

Yb-doped Fibers

(Low Dose Rate, Moderate Total Dose)

- Data shows the radiation-induced loss in optical transmittance of a Yb1200-4/125 fiber after 2 krad (Si) total gamma exposure.
- Only slight wavelength dependence is observed in the radiation-induced transmittance loss.
- Total accumulated induced optical losses as low as ~5%.

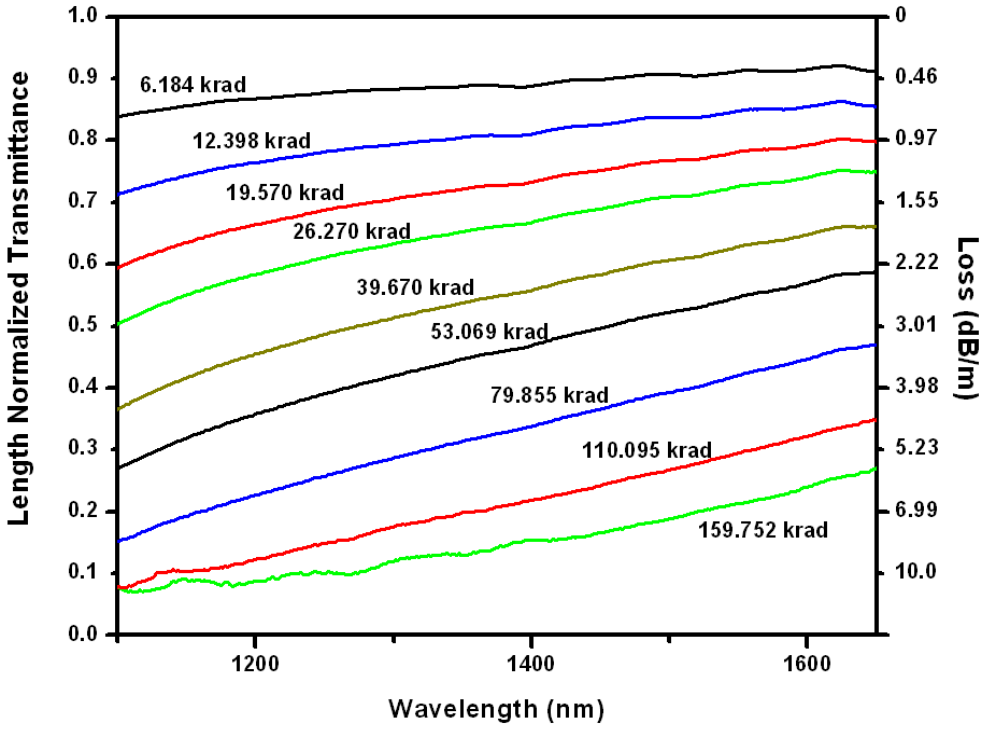


**Data reported accounts for removal of lamp spectrum and background losses arising from fiber pigtails and delivery fibers.*

- Dose rate = 14.3 rad/sec

Yb-doped Fibers
(Low Dose Rate, Large Total Dose)

- Representative data shows the effect of *large* accumulated doses of gamma radiation on the normalized optical transmittance of a Yb1200-4/125 fiber.
- Wavelength dependence of radiation-induced optical losses visible at large total doses.
- Complete photodarkening observed at highest total dose.



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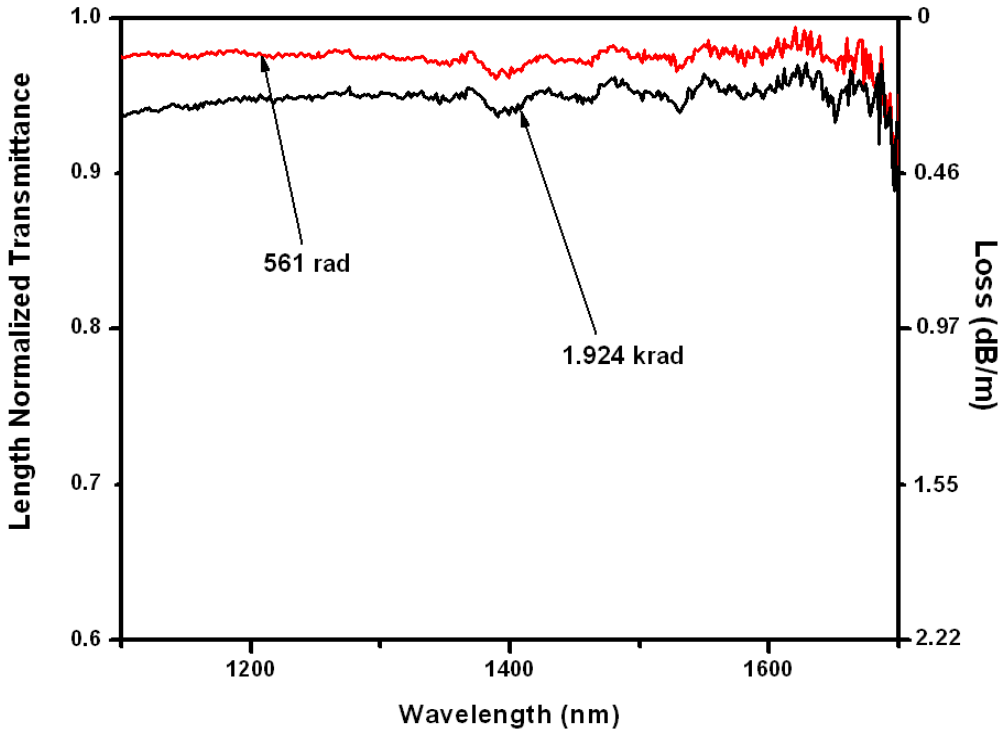

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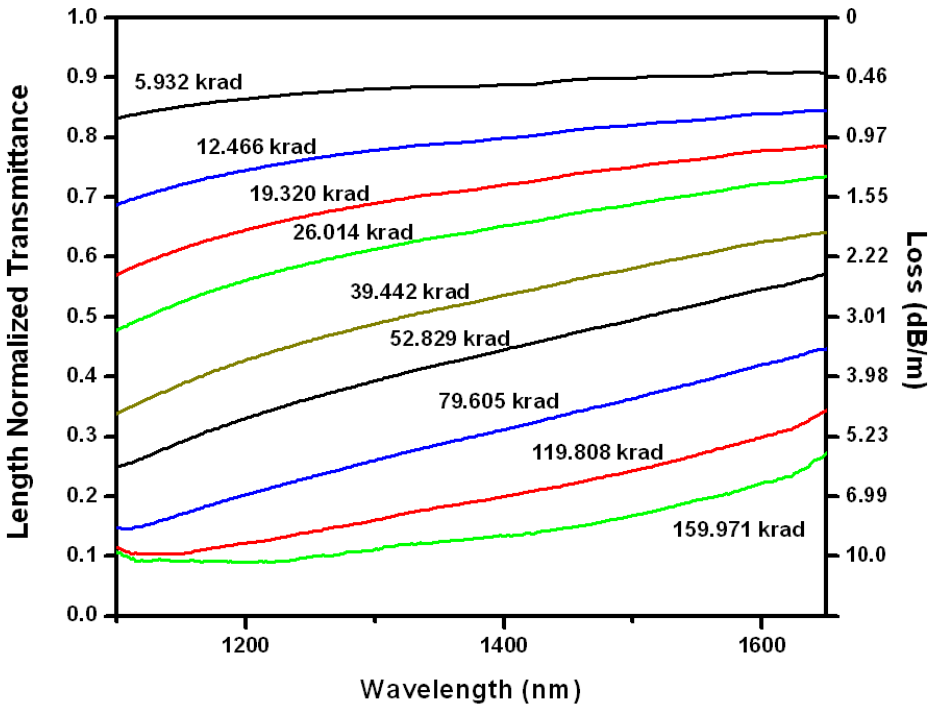

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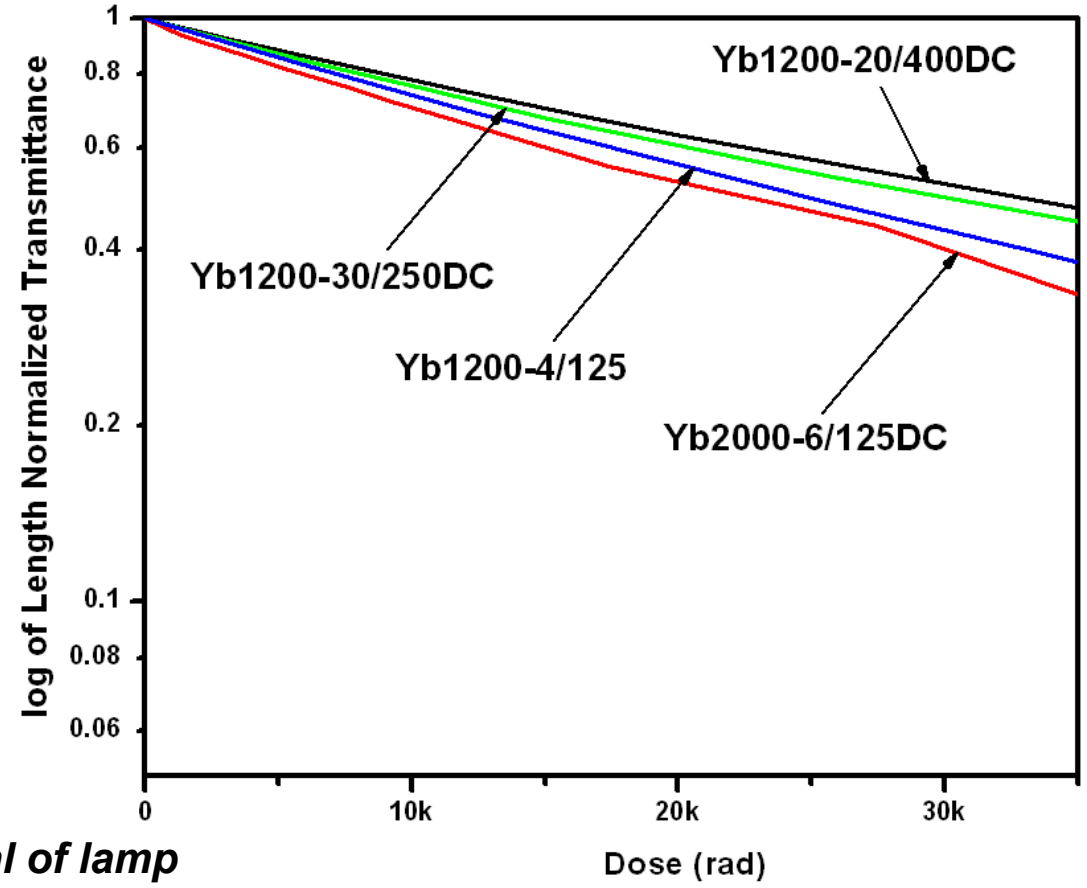
Transmittance Decay with Accumulated Dose

- Decay of optical transmittance for Yb-doped fibers at 1.1 μm.

- Radiation-induced optical transmittance reduction is roughly exponential in nature.



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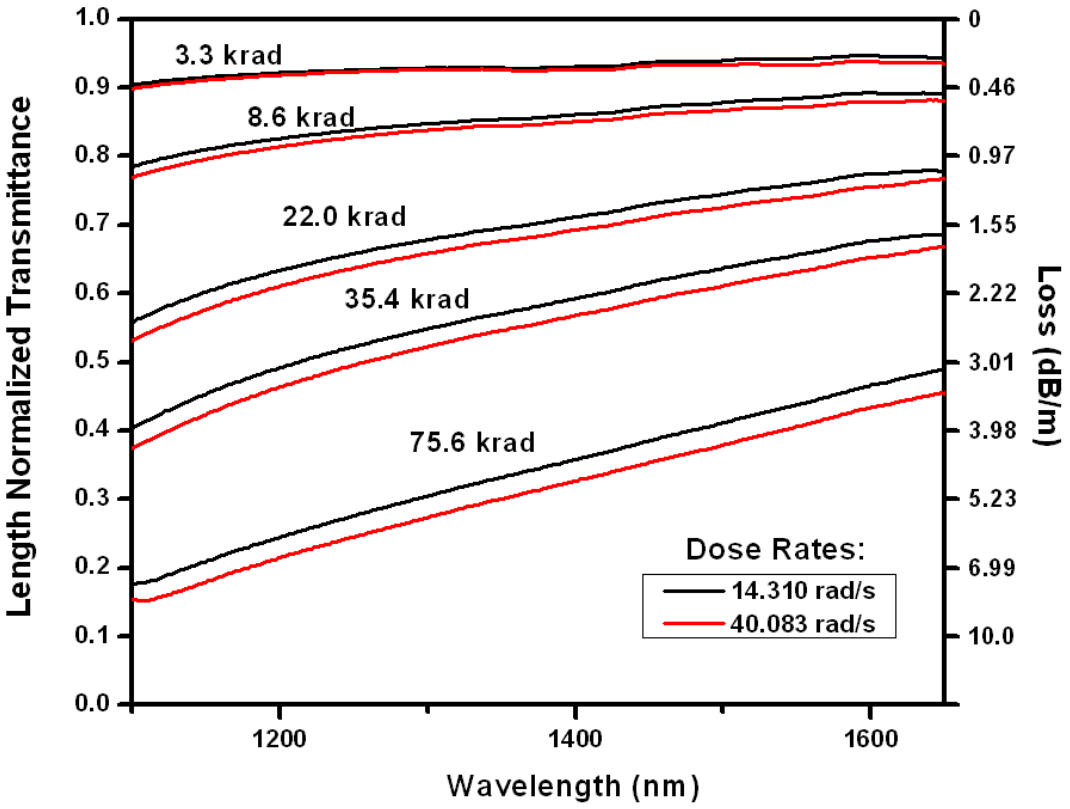
Effect of Dose Rate



- **Optical transmittance measurements for Yb1200-4/125 fibers exposed to two distinct dose rates.**

- **Up to a 10% increase (relative change) observed in measured optical transmittance loss at higher dose rate.**

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Summary of Results and Conclusions

- All doped-fibers exhibited some extent of radiation-induced photodarkening.
- Yb-doped fibers yielded only small transmittance losses, 5-10% total loss at all wavelengths, following 2 krad (Si) total gamma exposure.
- Effect of dose rate observed in all fibers.
  - Functional dependence data *essential for accurate simulation of deployment conditions.*

Overall, doped fibers exhibited good gamma radiation resistance in the anticipated deployment environments.