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Qualification of Fiber Optic Cable for NPP

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Fiber optic cables become more and more important in the nuclear industry.

Fiber optic instrument channels in nuclear power plants offer several advantages over traditional electrical conductor, including:

- increased immunity to electromagnetic interference (EMI),
- high transmission bandwidth,
- smaller size.

Increasing the use of fiber optic instrumentation in other industries has resulted in lower costs and a wider range of product availability.

Fiber optic at Dukovany NPP

Fiber optic cables are commonly used on I&C systems, usually in a mild environment.
For example at Czech NPP Dukovany, which is PWR type with four 440 MW units, 1330 optical cables have been installed. Some of them are on safety systems, the majority are not safety-related. Most of the optic cables are in a mild environment, few of them are located in a harsh environment without radiation.

Number of optical cables	Type	Total length	Note
596	Safety-related	26.2 km	Longest cable 200 m, Usually shorter, up to 100 m
734	non safety-related	50.5 km	Longest cable 550 m, Lengths over 200 m often

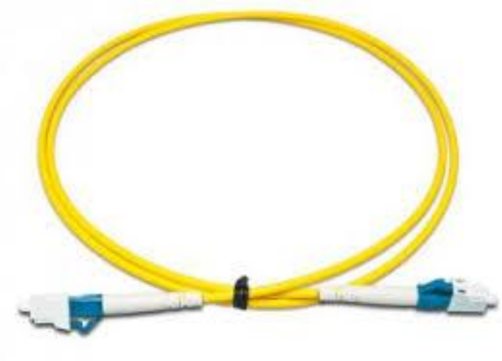
Application of safety-related fiber optic cables in a harsh environment with demand on functionality during LOCA needs their qualification.

The international standard for qualification IEEE 1682-2011: Standard for Qualifying Fiber Optic Cables, Connections, and Optical Fiber Splices for use in Safety Systems in Nuclear Power Generating Stations

This standard was issued first time in 2011, but it was approved as a full-use standard in the middle of 2013.

Critical parts of IEEE 1682 - samples

- **Required minimum length (Chapter 6.4.2):**
  "the minimum effective sample length 3 m."
  - *"As a minimum, 10 fibers from each cable sample shall be tested for the purpose of optical performance or signal integrity type tests. For those cable samples with fewer than 10 fibers, all fibers shall be tested and enough unique cable samples will be tested to gain at least 10 separate measurements for each fiber type."*

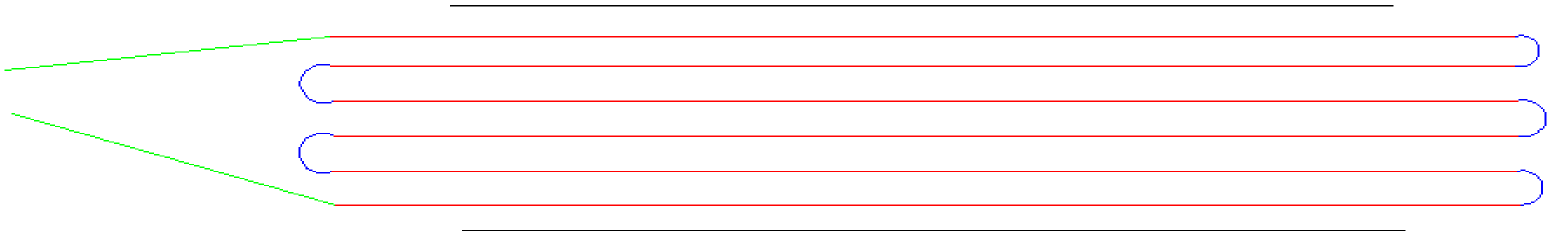


10 short samples

1 long sample

Critical parts of IEEE 1682 - samples

- The individual fibers in 24 F breakout cable were spliced together by fusion. 10 individual fibers from one 20 m long cable were connected in series. It was measured one 200 m long fiber originated from 10 fibers connected in series.



Critical parts of IEEE 1682 - ageing

- **Thermal ageing should be performed at the maximum humidity conditions specified for normal service conditions (Chapter 6.4.2.b):**

  - When the thermal ageing is carried out above the temperature 100°C the humidity level can't be regulated at normal atmospheric pressure. To follow strictly the standard, the ageing shall be carried bellow 100 °C, which will prolong the ageing time.

Critical parts of IEEE 1682 – seismic test

- **Connection assemblies shall be seismically qualified using the test methods described in IEEE Std 344- 2004. The connection assembly mounting for this test shall simulate the intended service configuration and installed conditions including consideration of external cabling (Chapter 6.4.4):**
  - Permanent connections that are made using the method of fusion **splices** are not mentioned. Our preliminary experience shows fusion sensitivity to irradiation. Hence, we would recommend performing a seismic test also on fiber fusions.

Fiber optic cable qualification

- Initial functional tests
- Accelerated thermal ageing
- Functional tests after TA
- Accelerated radiation ageing
- Coiling around the mandrel (20xD)
- Post-radiation effect tests
- Accident condition simulation
- Final functional tests
- Flame tests

Functional tests

- **Attenuation measurement (IEEE 1682: most important property)**
  - LSPM – Light Source and Power Meter (Insertion Loss)
  - OTDR – Optical Time Domain Reflectometer (Backscattering)

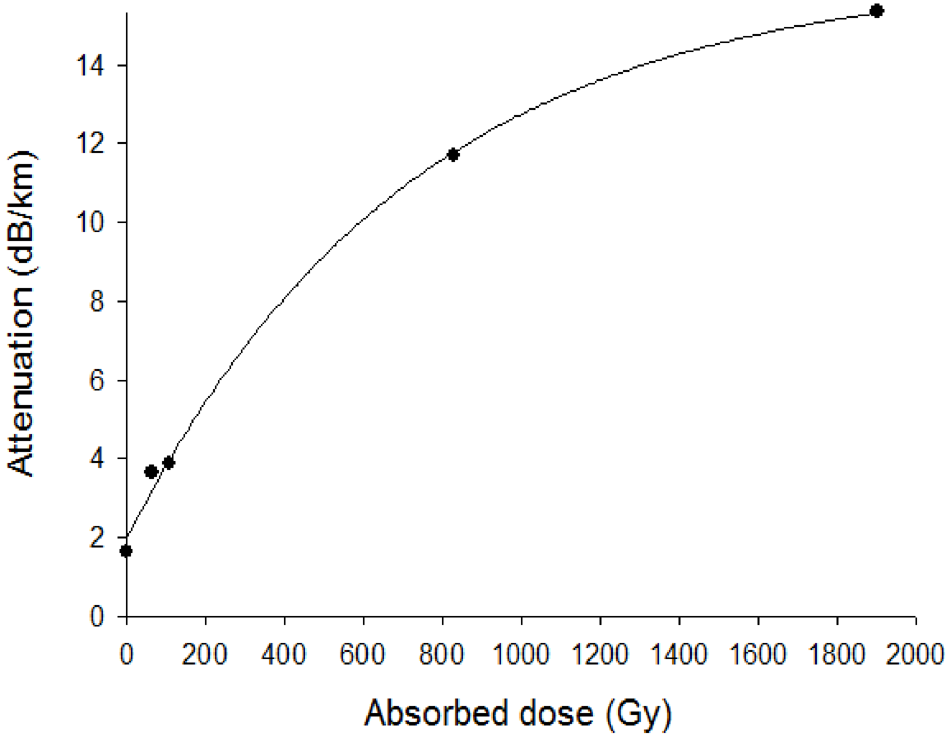
Sequence of measurement:

- Initial measurement
- After thermal ageing
- During radiation ageing (darkening!!)
- After irradiation, some days due to signal recovery (RIA)
- During accident dose irradiation
- Final test

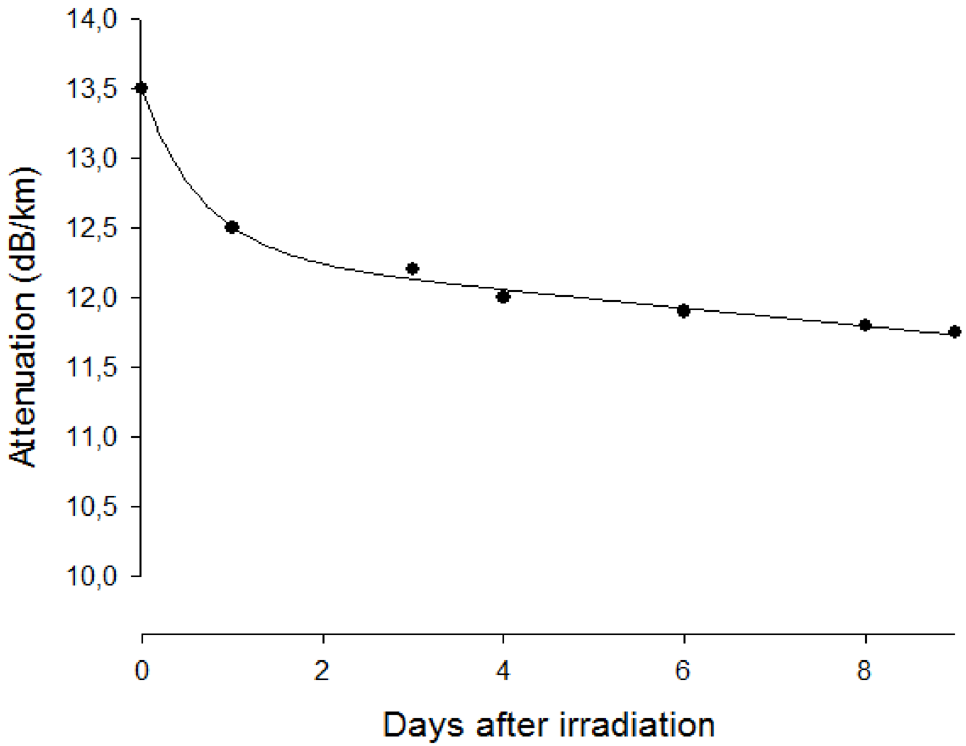
- **Other properties**
  - DTST (Distributed strain and temperature sensor)
  - Numerical aperture
  - Tensile test

Influence of gamma-irradiation on glass fiber

Irradiation – Darkening Process



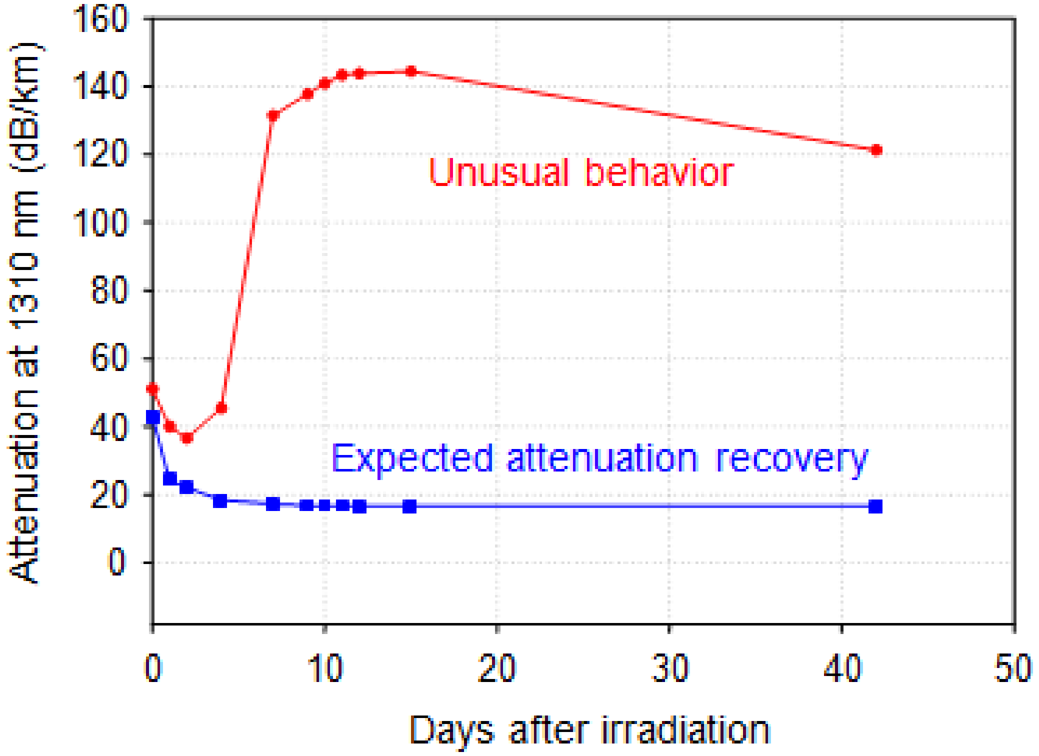
Recovery Process – Relaxation



Observed phenomenon – inverse recovery process

Possible reasons

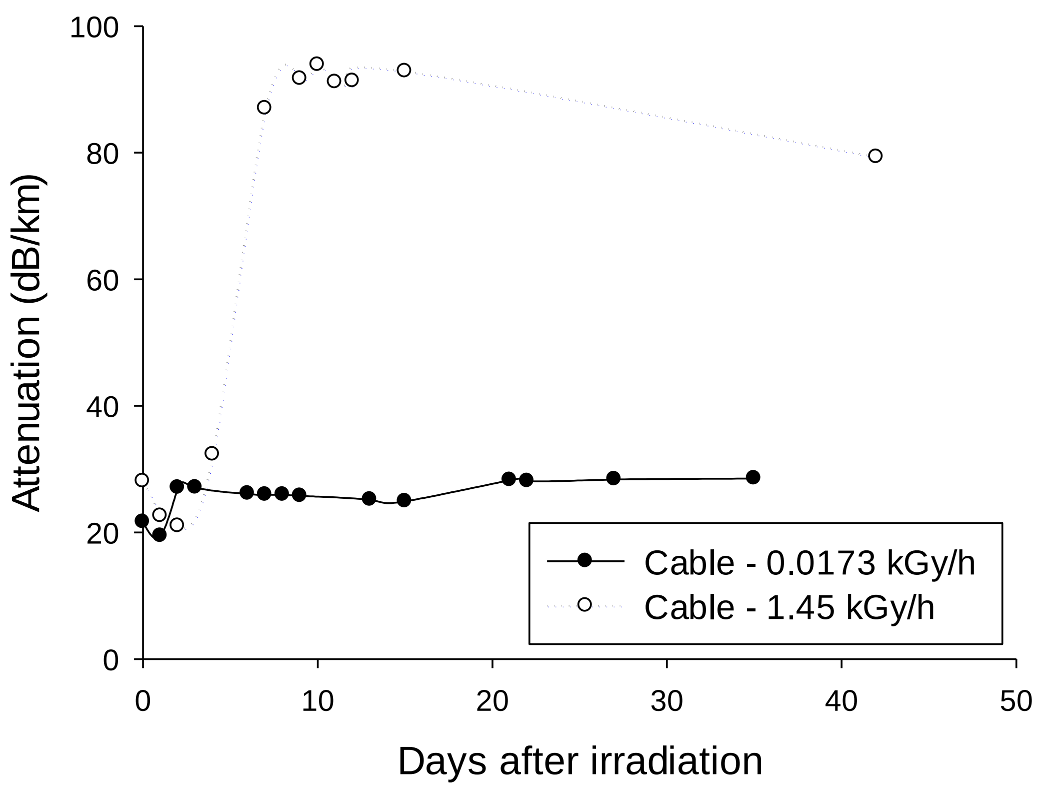
- Problem is in connectors and not in the cable itself.
- Ge dopant in the SM fiber.
- Mechanical stress. After irradiation, the cables must be straightened and coiled around a cylinder with a diameter similar to maximal allowed bending radius.
- The dose rate of irradiation. During the operation, the cables are irradiated at very low dose rates, while irradiation in the laboratory uses much higher ones. Is there any dose rate effect?
- Total dose. MM cable was irradiated with a ten times lower dose.
- Different cable construction, used materials, fibers (MM vs. SM), tubes, jelly etc.
- Some stress encountering during the manufacturing process.
- Other.

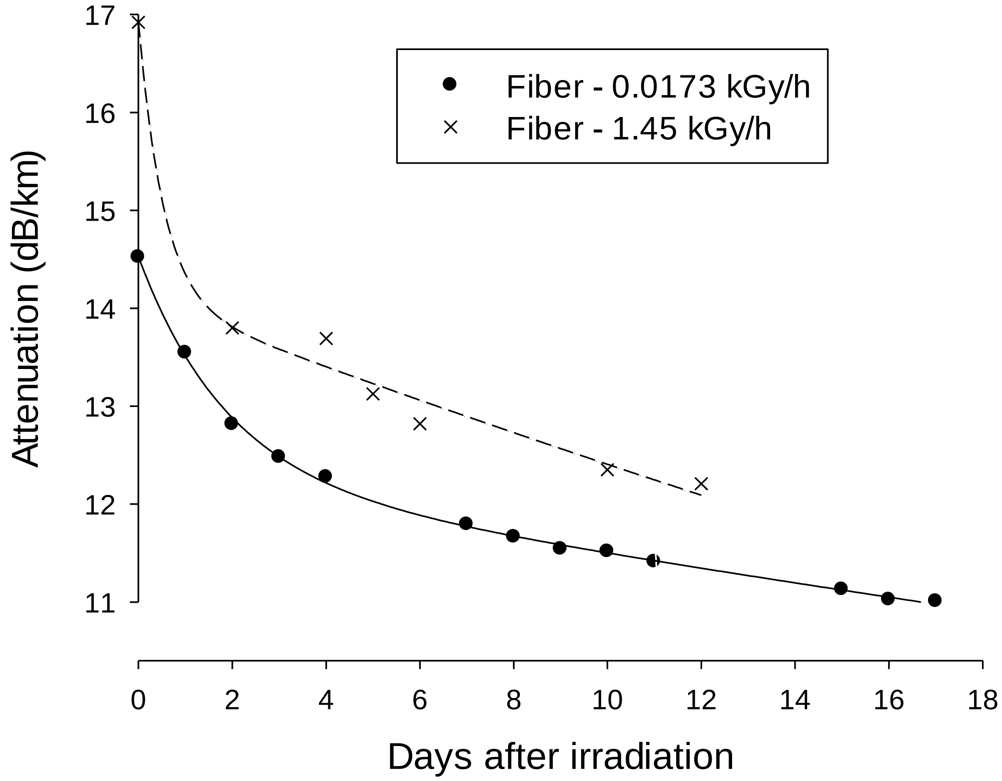


Checking qualification process

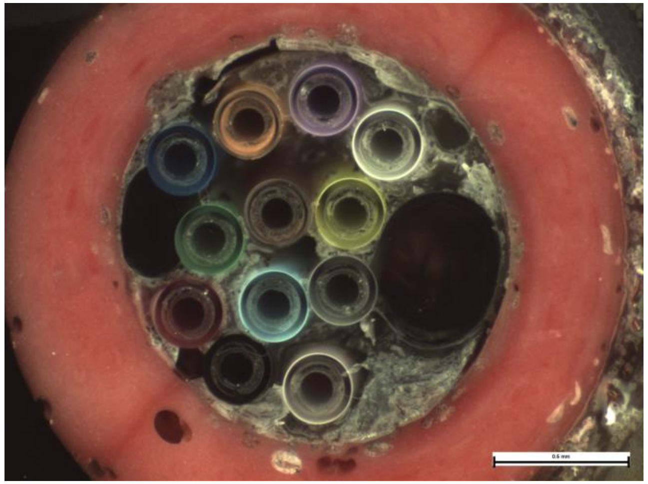
- **Influence of connectors and fusions irradiation**
  - Cables ends were shielded and/or pulled out of the irradiation facility.
- **Thermal ageing**
  - For comparison, cables were irradiated without any thermal treatment, too.
- **Mechanical stress. After irradiation, the cables must be straightened and coiled around a cylinder with a diameter similar to maximal allowed bending radius.**
- **Total dose. MM cable was qualified with ten times lower dose.**
  - Irradiation of MM cables to similar radiation dose.
- **Dose rate of irradiation.**

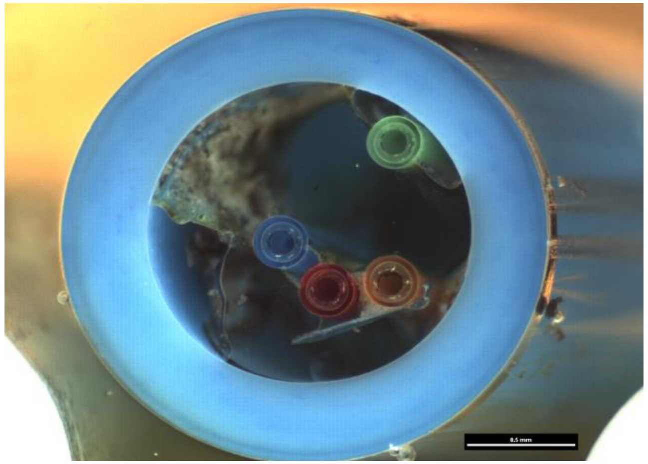
Dose rate effect

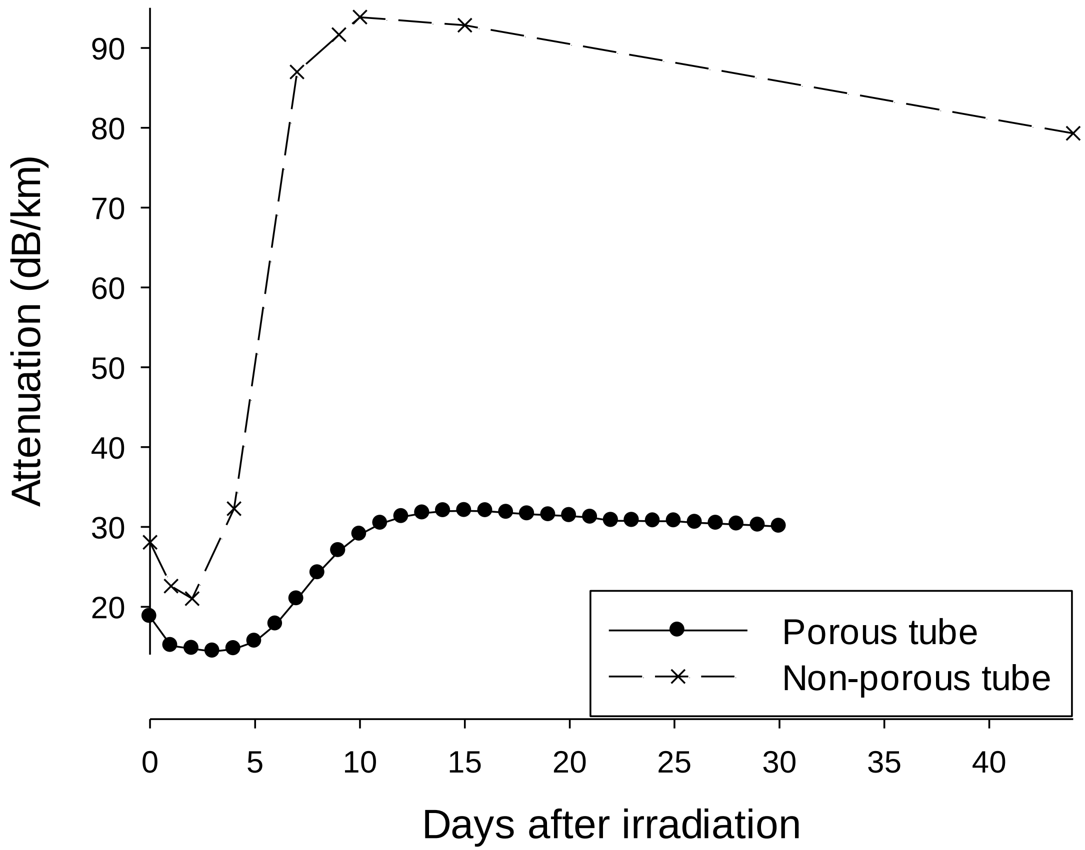




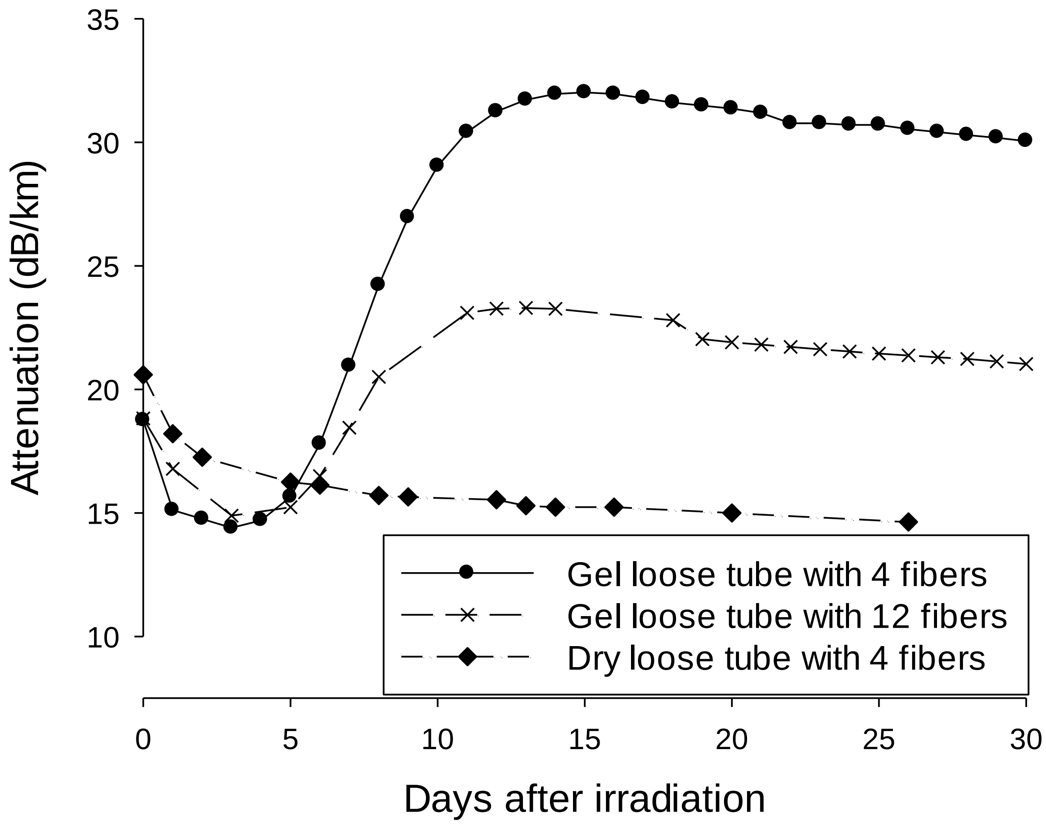
Effect of loose tube material

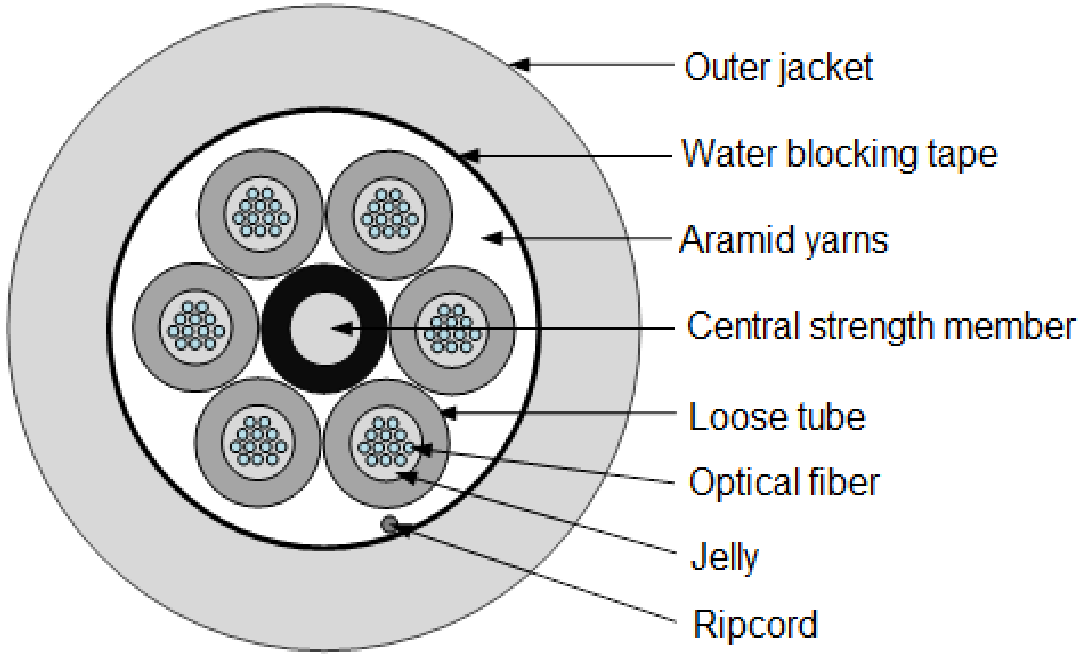






Types of loose tubes effect





Conclusion

- Qualification of optical cables will become increasingly common
- The standard IEEE 1682 is the first international standard that covers the basic procedure of qualification testing for fiber optic cable operating in the harsh environment of NPP.
- This presentation discusses some practical testing experience open questions and problems that are not included in the standard, or not prescribed properly.

- In ÚJV, we discovered an unusual phenomenon “inverse recovery process”
- It has been proved, that
  - The glass material of used fiber,
  - mechanical stress,
  - radiation dose rate
  - The material of the loose tube

do not cause the inverse recovery process.

- We suppose that this is caused by cable construction. The jelly probably goes through some physical and/or chemical changes and causes the inverse recovery process.
  OR
  Radiation creates hydrogen species that can go through the fiber coating up to the fiber core, interact with created point defects and create Si-OH.

Acknowledgement

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Thank you for your attention

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