

Radiation Hardness of μ -Coax cable

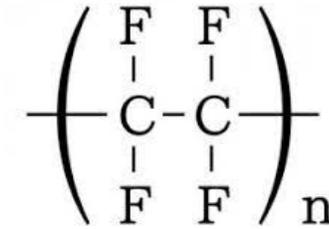
RIKEN/RBRC

Itaru Nakagawa

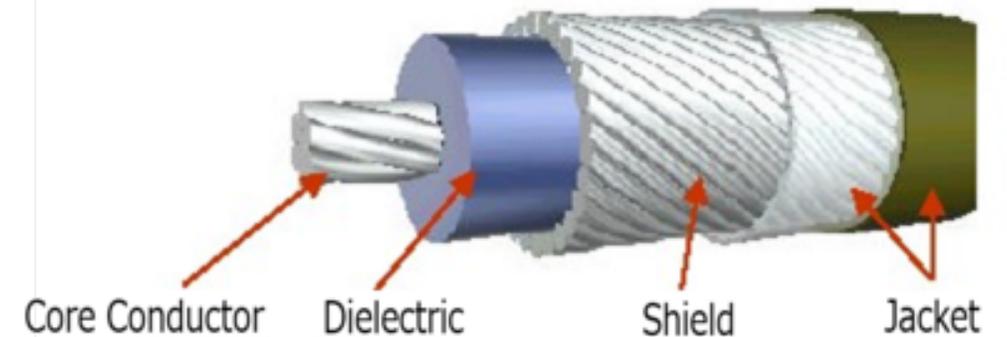
μ-Coax Cable Structure and Material

2. Construction and material Material Breakdown of micro-Coax

Item	Unit	Specified Value
Inner conductor	Material	Silver plated Copper Alloy wire
	AWG size	44
	Stranding	No./mm
	Dia. (approx.)	mm
Insulation	Material	PFA
	Thick.(nom.)	mm
	Dia. (approx.)	mm
	Color	-
Outer Conductor	Material	Tinned copper alloy wire
	Type	Wrap(Right-hand lay)
	Strand Dia. (approx.)	mm
	Material	PFA
Jacket	Thick.(nom.)	mm
	Dia. (Max.)	mm
	Color	-
		Brown , Green



PTFE 化学式



PFA (フッ素樹脂) =パーフルオロアルコキシアルカン
 四フッ化エチレン・パーフルオロアルコキシエチレン共重合樹脂

Fleoropolymer Types

<http://www.differencebetween.net/science/chemistry-science/difference-between-pfa-and-ptfe/>

フッ素樹脂の種類

<p>So called “Teflon”</p> <p>PTFE《ポリテトラフルオロエチレン》 日本語の名称は四フッ化エチレン樹脂。 フッ素樹脂というとPTFEを指す場合が多く、生産量、使用量ともにフッ素樹脂の中では1番多いです。</p>	<p>PTFE</p> $\left[\begin{array}{cc} \text{F} & \text{F} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{F} & \text{F} \end{array} \right]_n$
<p>PFA《パーフルオロアルコキシアルカン》 日本語の名称は四フッ化エチレン・パーフルオロアルコキシエチレン共重合樹脂。 PTFEに匹敵する特性を持ち、溶接加工、成形が可能。</p>	<p>PFA</p> $\left[\begin{array}{cc} \text{F} & \text{F} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{F} & \text{F} \end{array} \right]_m \left[\begin{array}{cc} \text{F} & \text{F} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{O} & \text{F} \\ & \\ \text{F}-\text{C}-\text{F} \\ \\ \text{F} \end{array} \right]_n$
<p>FEP《パーフルオロエチレンプロペンコポリマー》 日本語の名称は四フッ化エチレン・六フッ化プロピレン共重合樹脂。 PTFEに比べると耐熱性は劣りますが、溶接成形が可能で他の特性もPTFEについて優れています。</p>	<p>FEP</p> $\left[\begin{array}{cc} \text{F} & \text{F} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{F} & \text{F} \end{array} \right]_x \left[\begin{array}{cc} \text{F} & \text{F} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{F} & \text{F} \\ & \\ \text{F}-\text{C}-\text{F} \\ \\ \text{F} \end{array} \right]_n$
<p>ETFE《エチレンテトラフルオロエチレンコポリマー》 日本語の名称は四フッ化エチレン・エチレン共重合樹脂。 溶接成形が可能で、機械的特性が他のフッ素樹脂より優れています。 電気絶縁性、耐放射線性、耐薬品性、低温特性も良好です。</p>	<p>ETFE</p> $\left[\begin{array}{cccc} \text{H} & \text{H} & \text{F} & \text{F} \\ & & & \\ -\text{C} & - & \text{C} & - & \text{C} & - & \text{C}- \\ & & & \\ \text{H} & \text{H} & \text{F} & \text{F} \end{array} \right]_n$

<https://www.yumoto.jp/material-onepoint/plastic-ptfe-pfa-pvdf>

Summary:

1. Both PFA and PTFE are fluoropolymers.
2. PTFE is the more commonly used fluoropolymer, and it is popularly known as “Teflon.”
3. PFA is melt processable and more versatile than PTFE, but PTFE is superior when it comes to being less water absorbent and resistant to weathering.
4. PFA is more often used in [industrial](#) applications, particularly with lab equipment and [industrial](#) tubing, but PTFE is more common and popular especially with cookware.

Let's assume PTFE and PFA are similar in terms of radiation hardness

Radiation Hardness of Fluoropolymer

<https://www.osti.gov/servlets/purl/1467983>

Dielectric material

Radiation Effects on Teflon Wires

LeRoy Whimery, Alexis Abelow, Wei-Yang Lu, Karla Reyes, Donald Ward, Dustin Murtagh, Zachary Meinhart, Nathalie Le Galloudec, Al Ver Berkmoes, Raymond Friddle

Problem

- Nuclear Safety Assurance asked a question along the lines of... "given that Teflon is the most radiation sensitive polymer used in NW, how do we know that the Teflon insulation of the wires exposed to radiation for decades is not flaking off leaving the conductors without adequate insulation?"
- Given the context, a quick study to find a preliminary answer was needed.

Approach

- Perform electrical testing to ensure wires are behaving normally
- Remove cables from MCS01
- Remove the outer sheath from the cable
- Examine the cable/wires for discoloration
- Band the wire(s), look for cracks and record images
- Cut and prepare sample for nano-indentation
- Strip wire(s) and tensile test Teflon only

Radiation Damage Mechanism

The mechanism of Teflon degradation by radiation has been well studied. No C-C peaks observed in FTIR.

Polymer Radiation Sensitivity

Teflon is one of the most radiation sensitive polymers

Teflon Wire Bend Test

No cracks were observed when put in tension.

Quasi-Static Uni-Axial Tensile Testing

Nano-indentation

The hardness is calculated as the maximum load divided by the actual contact area made between the indenter tip and the material. Hardness is essentially the flow resistance a material is to deformation (elastic + plastic). The Modulus is the slope of the load-displacement curve upon unloading, divided by the root of the contact area. So modulus is the ratio of elastic stress to strain.

Results

Tensile testing showed ~25% reduction in strength and a significant reduction in elongation to failure. Substantial variability was observed, particularly in the elongation. This variability may be due to flaws introduced during sample preparation. Additional testing is underway to provide better statistics.

Sample	Material	Modulus (MPa)	Elongation (%)
PTFE 1	PTFE	1,250	2.31
PTFE 2	PTFE	2,500	14.57
PTFE 3	PTFE	5,000	23.15
PTFE 4	PTFE	10,000	34.72
PTFE 5	PTFE	30,000	68.44
Empty	Empty	5,000	23.15

Additional Dose Testing

Dosimeter Locations

Additional Radiation Exposure

- Expose the Teflon coated wires to additional radiation and examine their physical/mechanical properties.
- Determine how much additional exposure is needed to compromise their ability to provide electrical isolation.
- Samples are irradiated at the GJF using a Co-60 source.
- Dose rates from 10³ rad/s to over 10⁷ rad/s.
- Samples irradiated in an inert atmosphere (N₂).

Future Work

- High voltage breakdown and insulation resistance will be performed
- Additional radiation to look for a shift in the properties
- Vessels irradiated at GJF (AEG) (gamma)
 - 5mm/second (0.412 krad/hr)

Summary

- No discoloration was observed
- No cracking was observed upon bending (1/4" radius)
- Nano-indentation did not show any differences in hardness or modulus
- Elongation of Teflon appears to be sensitive to radiation
- Need to perform more tensile testing for better statistics

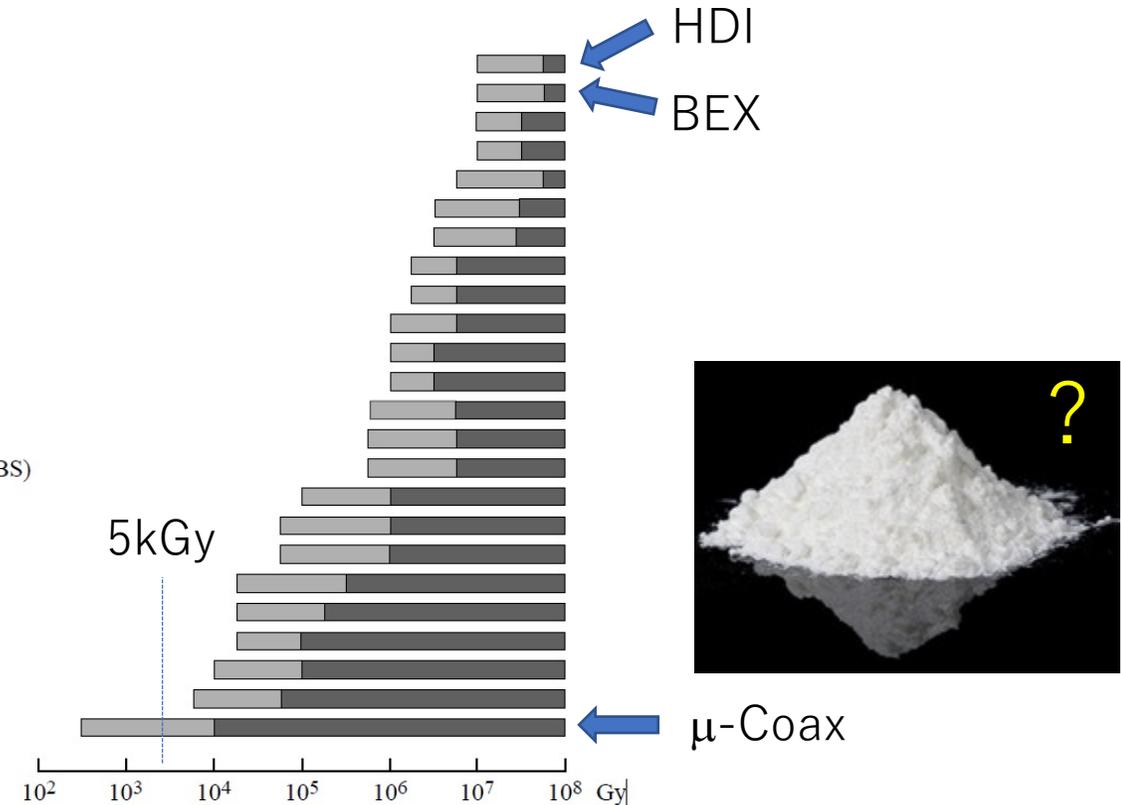
Tensile Testing of Insulation Only

Conductor removal for tensile testing - a possible source of variability (flaws)

- Wire strippers were used to remove a small amount of insulation.
- Files were then used to grab the copper conductors.
- Sliding my grip down the wire many times allowed it to slowly release from the insulation and be removed.
- Gloves helped with gripping the Teflon.
- Care was taken to not pull too hard or too fast.

hard

- Polyimide (PI)
- Liquid Crystal Polymer (LCP)
- Polyetherimide (PEI)
- Polyamideimide (PAI)
- Polyphenylsulfide (PPS)
- Polyetheretherketone (PEEK)
- Polystyrene (PS)
- Copolymer PI + siloxane
- Polyarylate (PAR)
- Polyarylamide (PAA)
- Polyethersulfide (PES)
- Polysulfone (PSU)
- Polyamide 4.6
- Polyphenyloxyde (PPO)
- Acrylonitrile-butadiene-styrene (ABS)
- Polyethylene (PE)
- Polyethyleneterephthalate (PETP)
- Polycarbonate (PC)
- Polyamide 6.6 (PA)
- Cellulose acetate
- Polypropylene (PP)
- Polymethylmethacrylate (PMMA)
- Polyoxymethylene (POM)
- Polytetrafluoroethylene (PTFE)

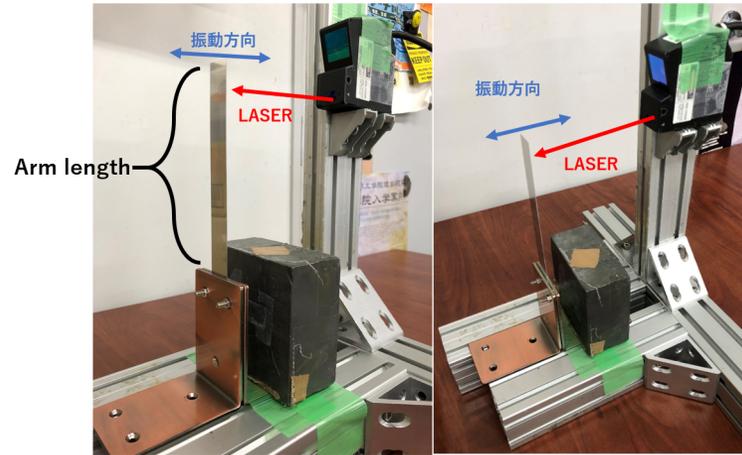


mild to moderate damage, utility is often satisfactory
 moderate to severe damage, use not recommended

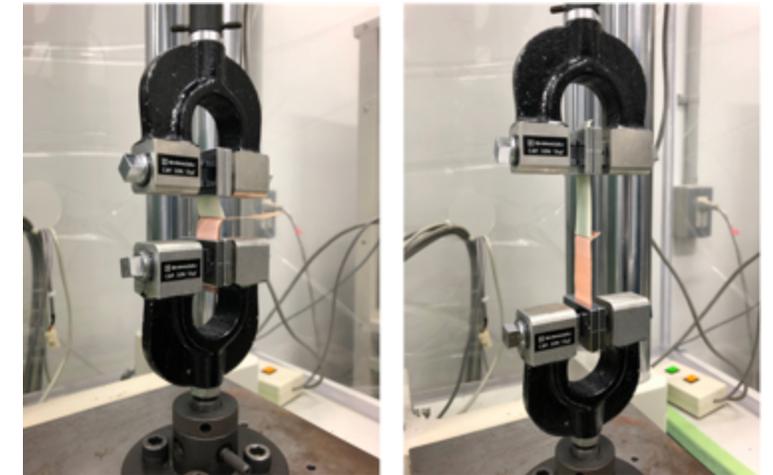
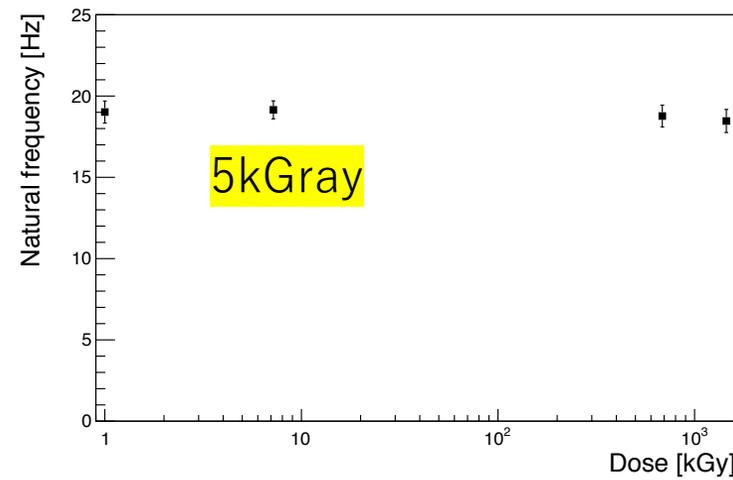
In general, fluoropolymer is known to to be weak against the radiation

Radiation Hardness of BEX

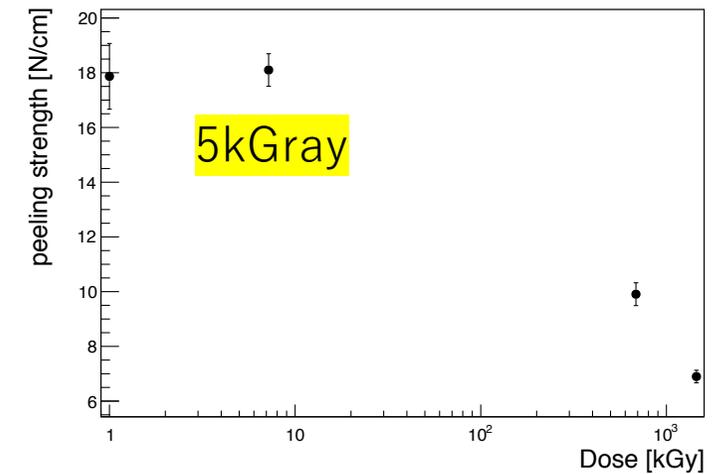
Hikaru Imai, Deploma Thesis (2021)



Rigidity Test

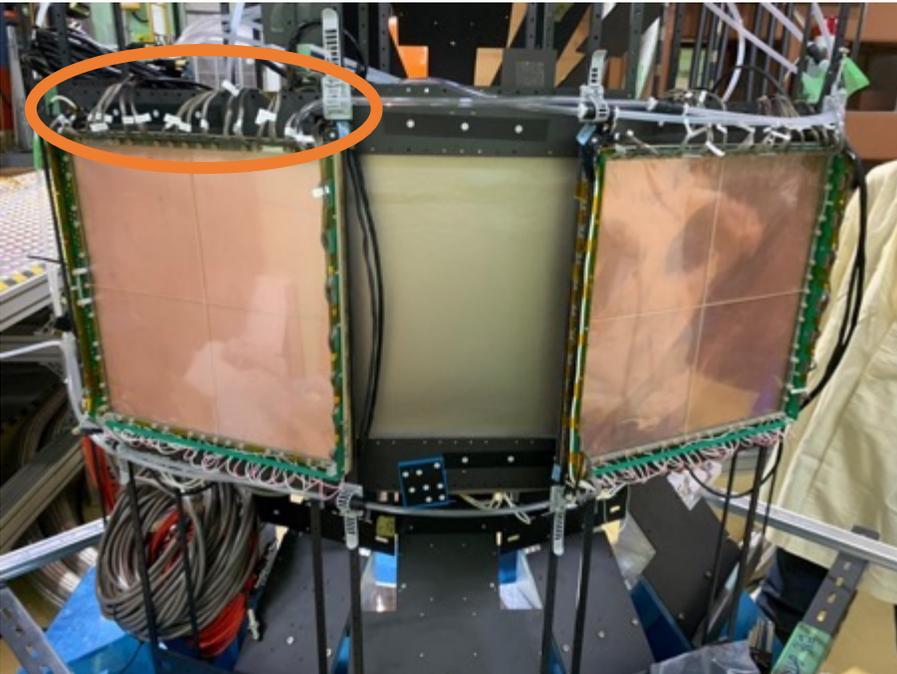


Peel Strength Test



No severe damage was observed within 5kGay gamma

μ -Coax used in J-Parc E16 Experiment



差出人 yokkaich@riken.jp ★

件名 Re: マイクロ同軸

宛先 (自分) <itaru@riken.jp> ★

Cc akiba@rcf.rhic.bnl.gov ★, hachiya@cc.nara-wu.ac.jp ★, yokkaich@riken.jp ★

返信

From: Itaru Nakagawa <itaru@riken.jp>

Subject: マイクロ同軸

Date: Mon, 14 Feb 2022 16:19:43 +0900

四日市様

マイクロ同軸の絶縁樹脂に放射線に対する劣化や性能低下はありますか？

ばう弱そ

もし過去

願います。

われわれの内輪ではstudyはしてないですね。

「実用後顕著な劣化」はみられていないですが。

オーダーで

Itaru: The PFA fluorinated resin used for the insulation and coating of micro coaxial is very susceptible to radiation. Is there any noticeable deterioration after practical use? Is there any noticeable degradation after practical use? If you have done any studies on radiation resistance in the past, please let me know. Thank you very much.

Yokkaichi: We have not done any study in our inner circle.

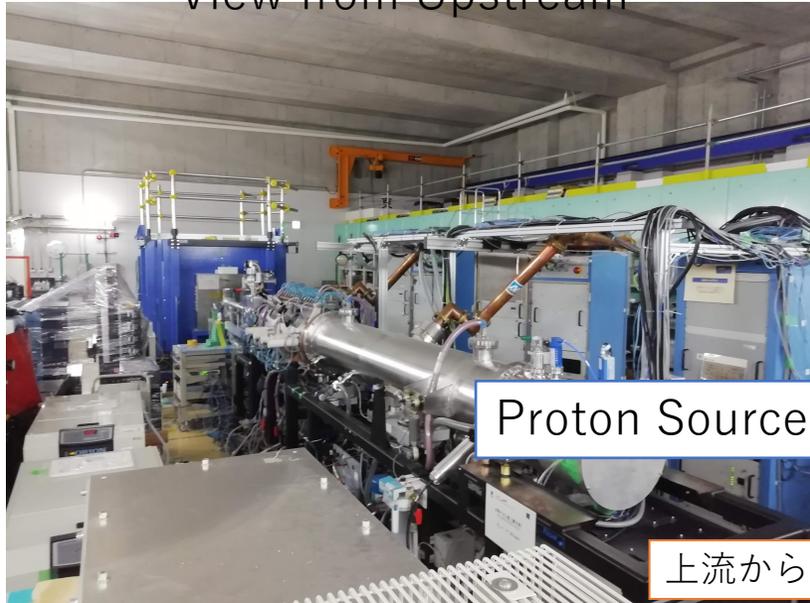
We have not seen any "significant degradation after practical use". Our radition dose is in the level of 10mSv/h * 24h * 30days = 7.2 Sv = 7.2 Gray so far.

Their radiation dose is orders of magnitude lower than what expected for 3 years of sPHENIX

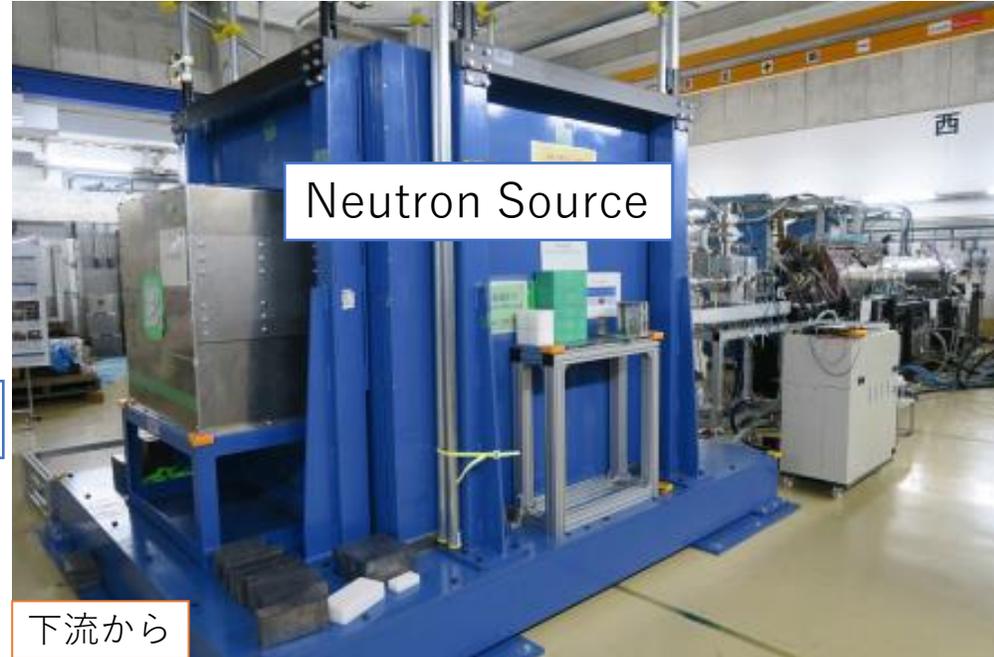
Any chance to expose m-Coax in Radiation?

RIKEN Accelerator-driven compact Neutron Source: RANS

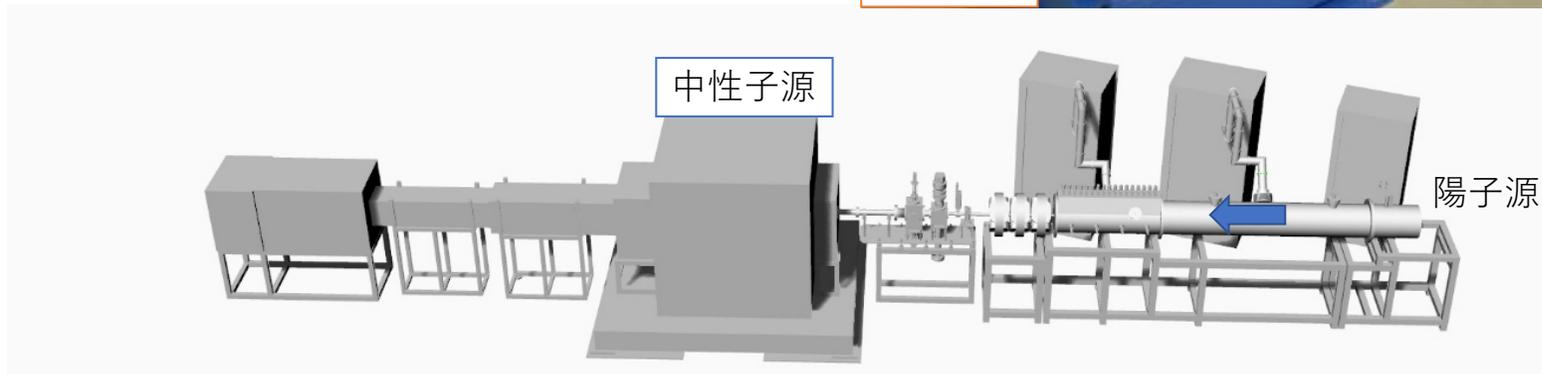
View from Upstream



View from Downstream



COMING UP



Beam Time for FoCAL@ALICE project in March 3-4, 2022. (10 hours)

What to do?



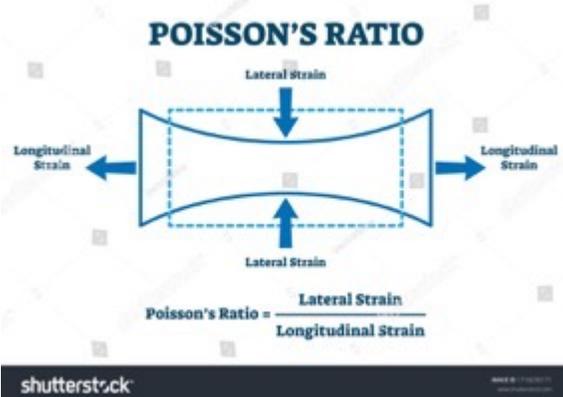
- Ask FoCAL team to let us parasite to their beam time.
- Try to irradiate (spare) micro coaxial cables with neutrons.
- How will we evaluate the performance before and after irradiation?
- The bending stiffness will be too soft to measure.
- I don't think it will be easy to measure peel strength either.
- Is it worth it just to check if the coating will be torn to pieces?
- Any way to quantify the radiation effect?

Quantifying Radiation Damage Effect

Ultrasonic Wave Measurement

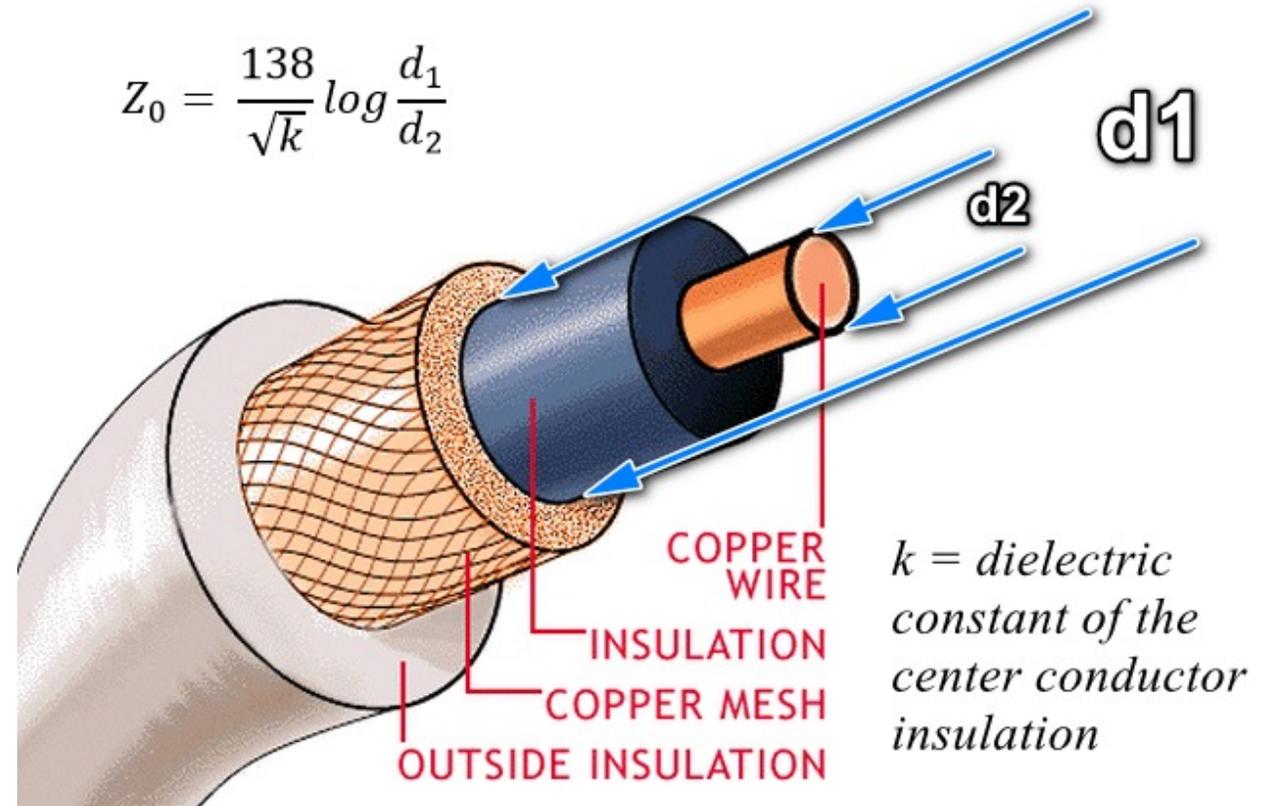
$$V_U = [(E/\rho) \times (1 - \nu)/(1 + \nu) (1 - 2\nu)]^{1/2}$$

Propagation speed of ultrasonic wave in the material of elasticity E , density ρ , and poisson's ratio ν .



Impedance Measurement

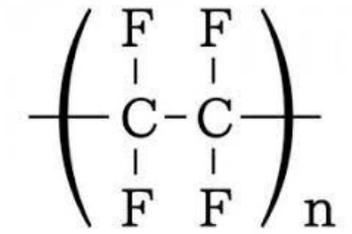
$$Z_0 = \frac{138}{\sqrt{k}} \log \frac{d_1}{d_2}$$



Any other idea?

Backup

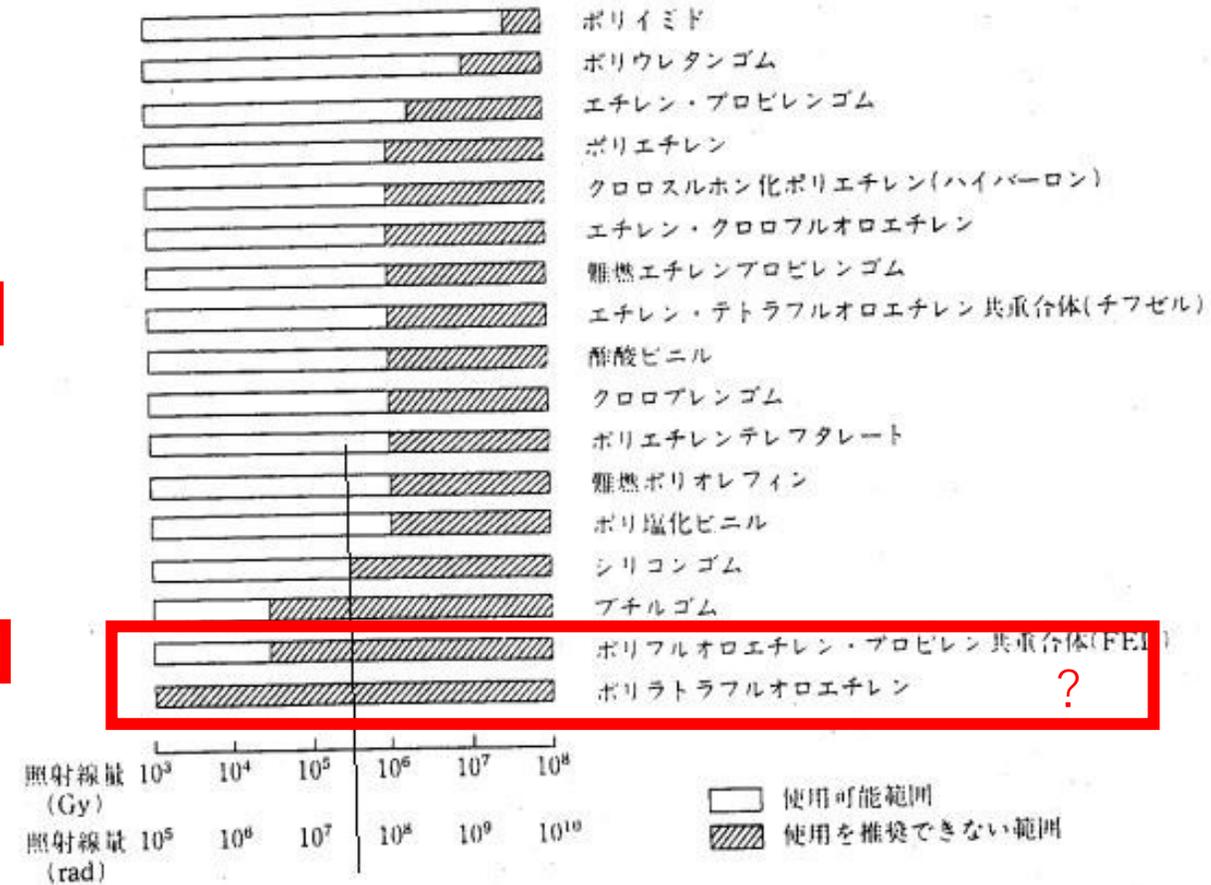
Micor-Coax Radiation Hardness



PTFE 化学式

2. Construction and material マイクロ同軸ケーブルのマテリアル

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	Type	Wrap(Right-hand lay)
	Strand Dia. (approx.)	mm
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Jacket	Thick. (nom.)	mm
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 四フッ化エチレン・パーフルオロアルコキシエチレン共重合樹脂

耐放射線性

放射線とはX線、 γ 線などの電磁波並びに α 線、 β 線、中性子線等の粒子線の総称。有機材料の場合、放射線による特性低下の原因は高分子鎖の間の結合(架橋)と分子鎖の切断及び二重結合等の不飽和結合の増大によります。有機材料では、力学特性が共通する特性であること、また電気特性の変化は一般的に力学特性が失われてから低下することが多いことから、引っ張り試験による破断強度と破断時の伸びの低下を耐放射性の評価基準としています。

<http://www.yohwa.co.jp/glossary.html>