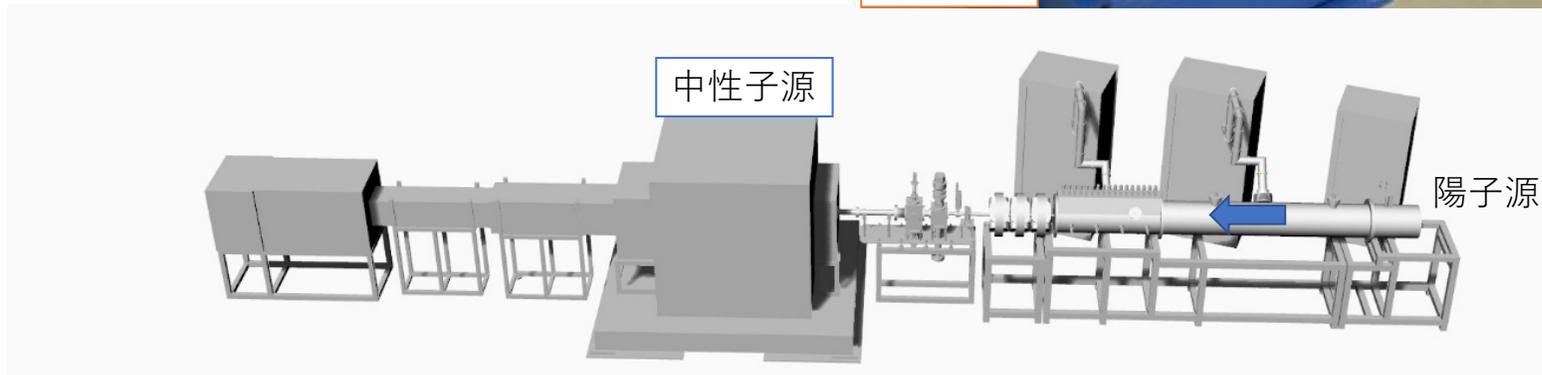


Radiation Hardness Test of μ -Coax cable at RANS

RIKEN/RBRC

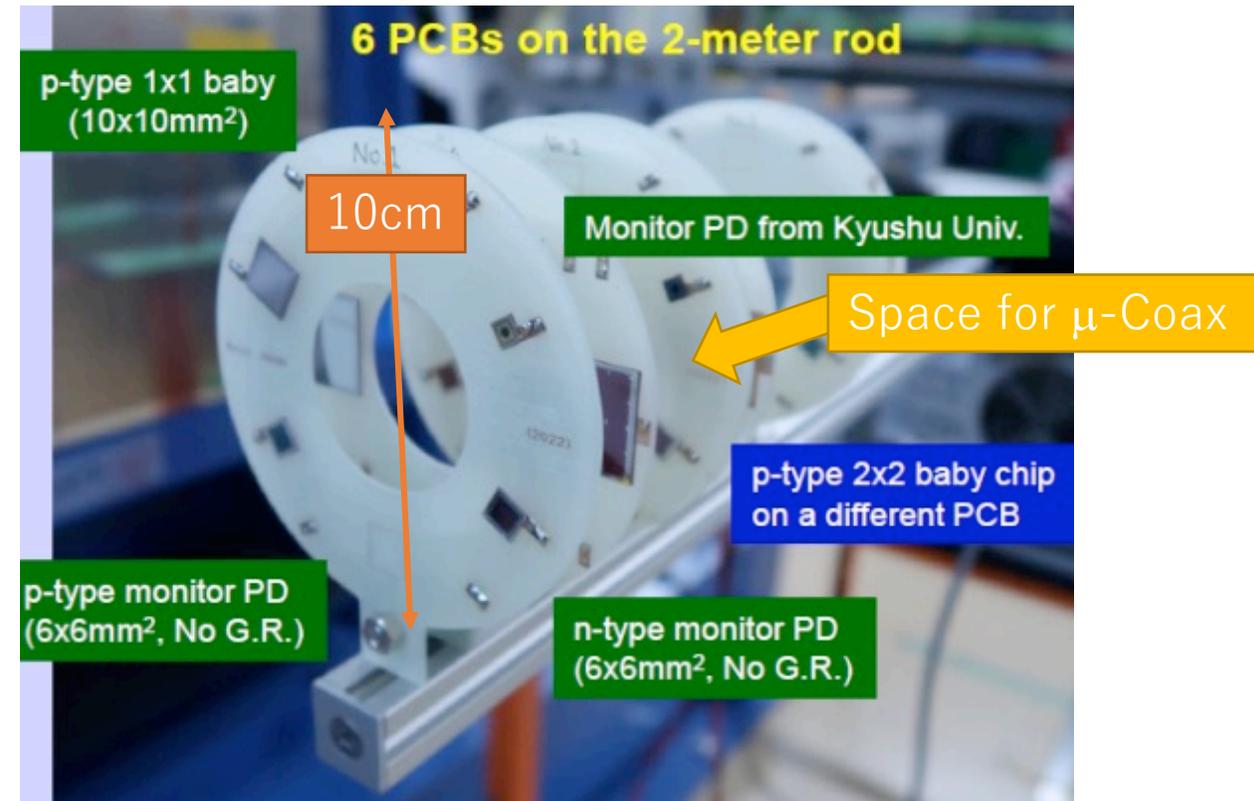
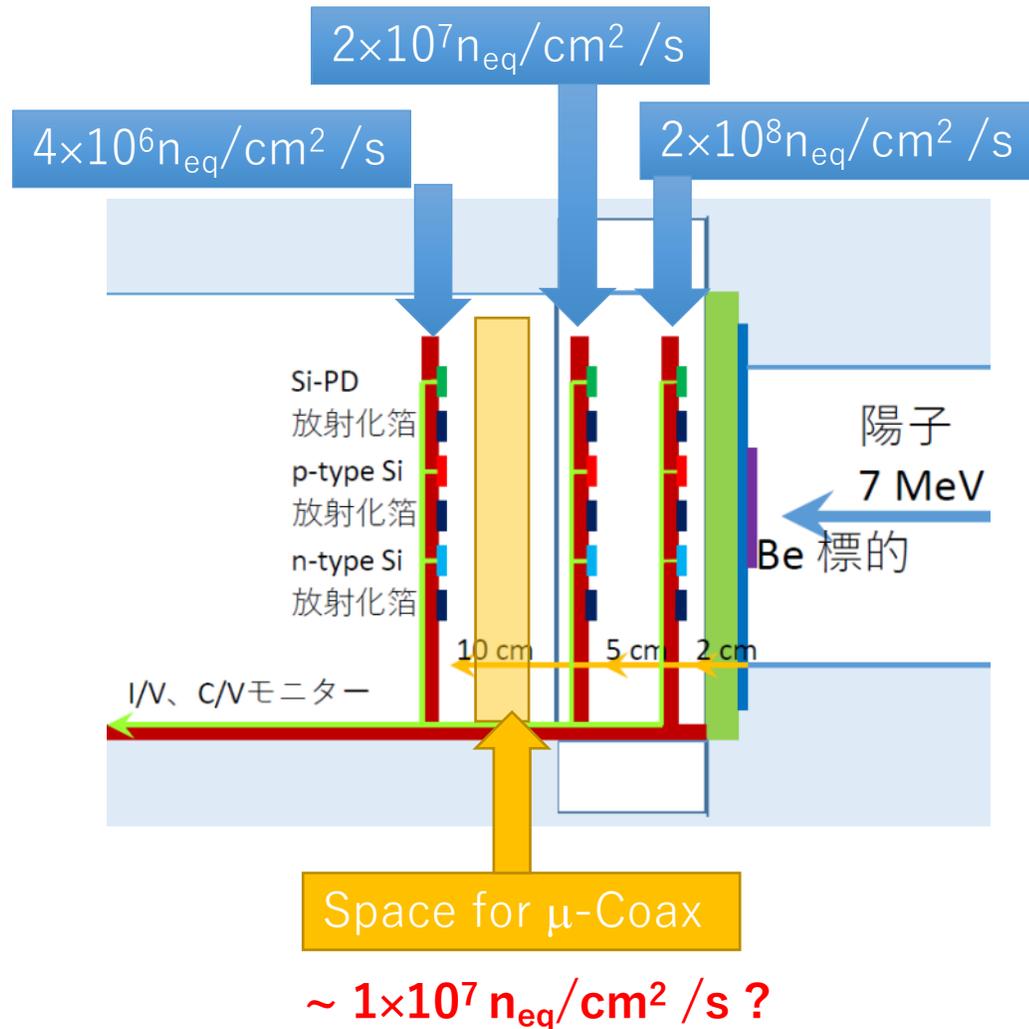
Itaru Nakagawa

小型中性子源：RANS (RIKEN Accelerator-driven compact Neutron Source)



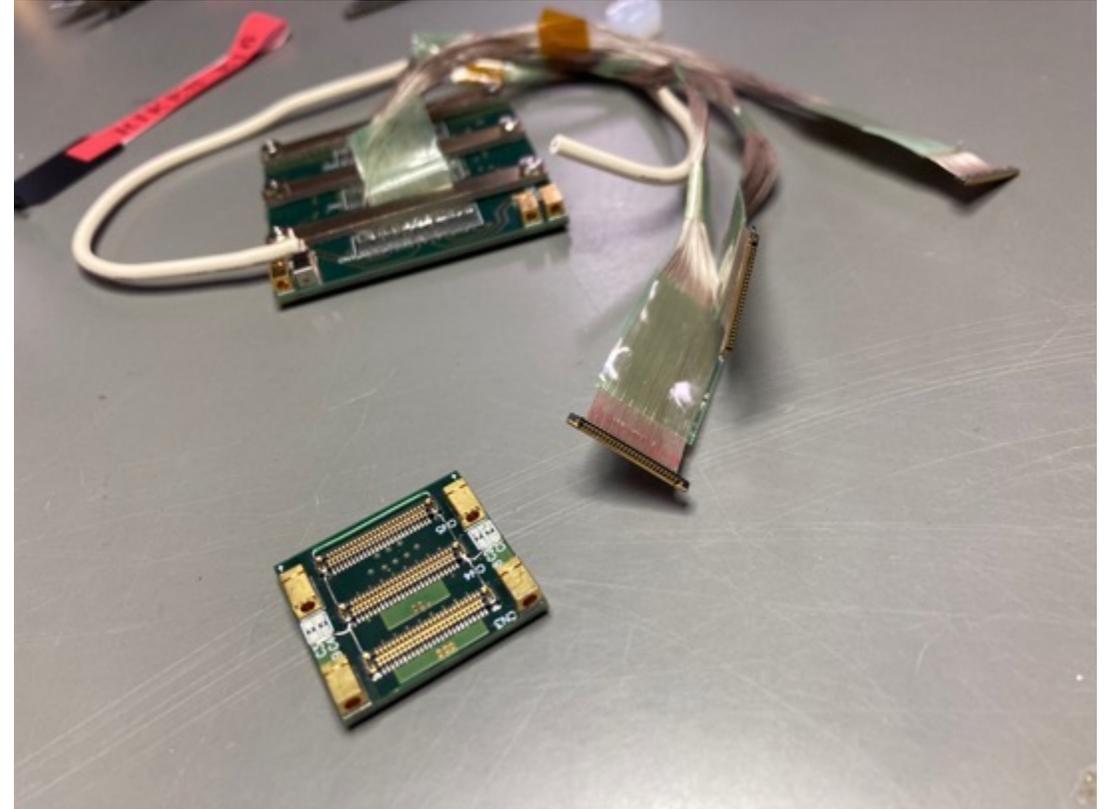
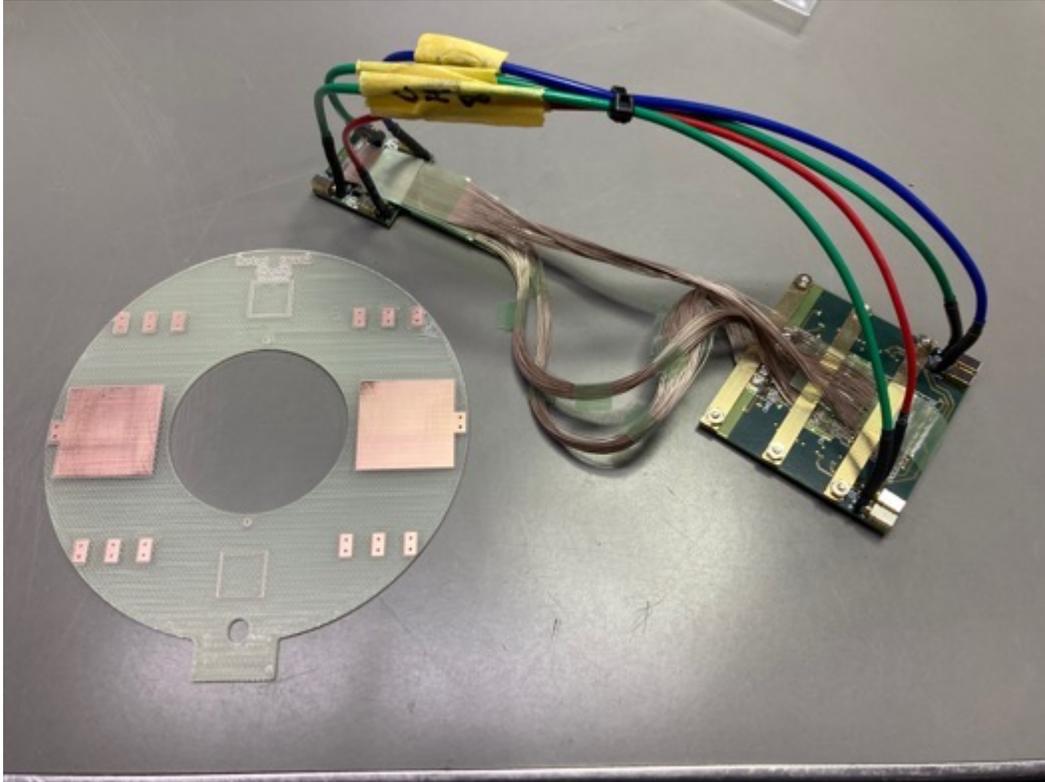
Beam Time for FoCAL@ALICE
project in March 3-4, 2022.
(10 hours)

Parasite to FoCAL@ALICE Experiment



FOCAL Radiation Exposure Setup

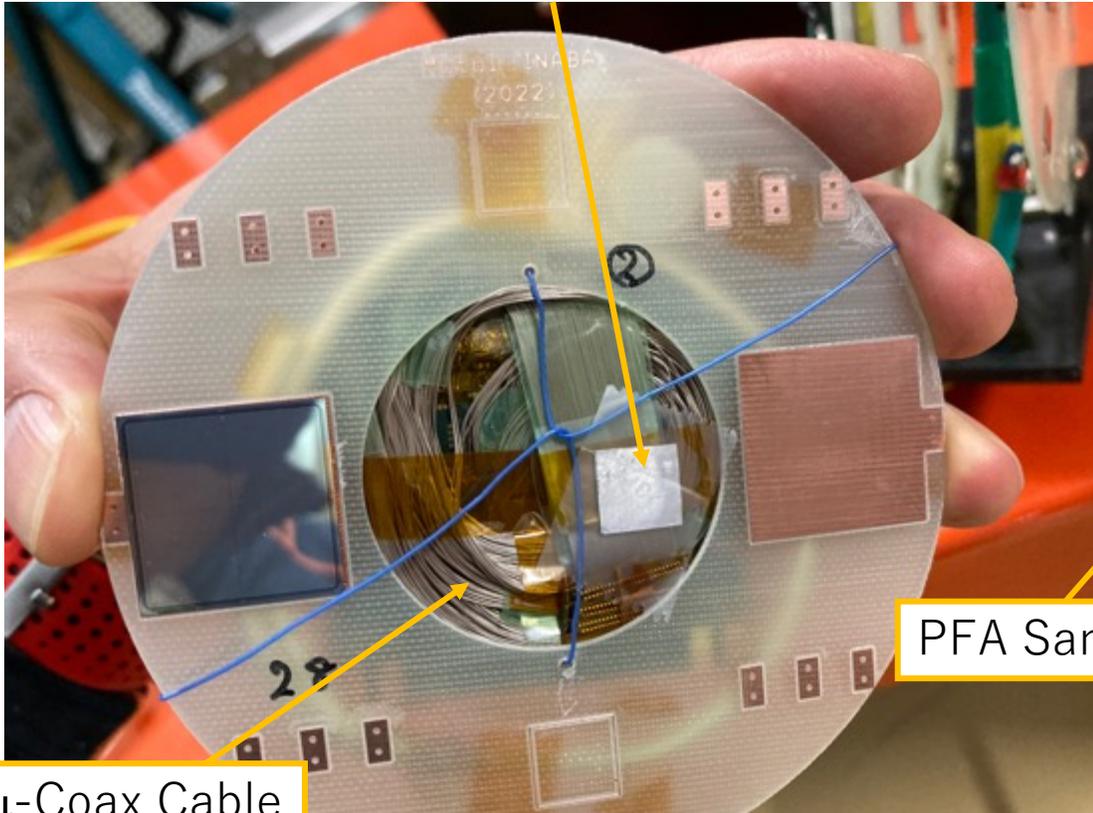
Prototype-I Cable Setup



Dismounted GND/Power cables and ROC side connector

Prototype-1 Cable Setup

Indium foil for absolute neutron flux measurement

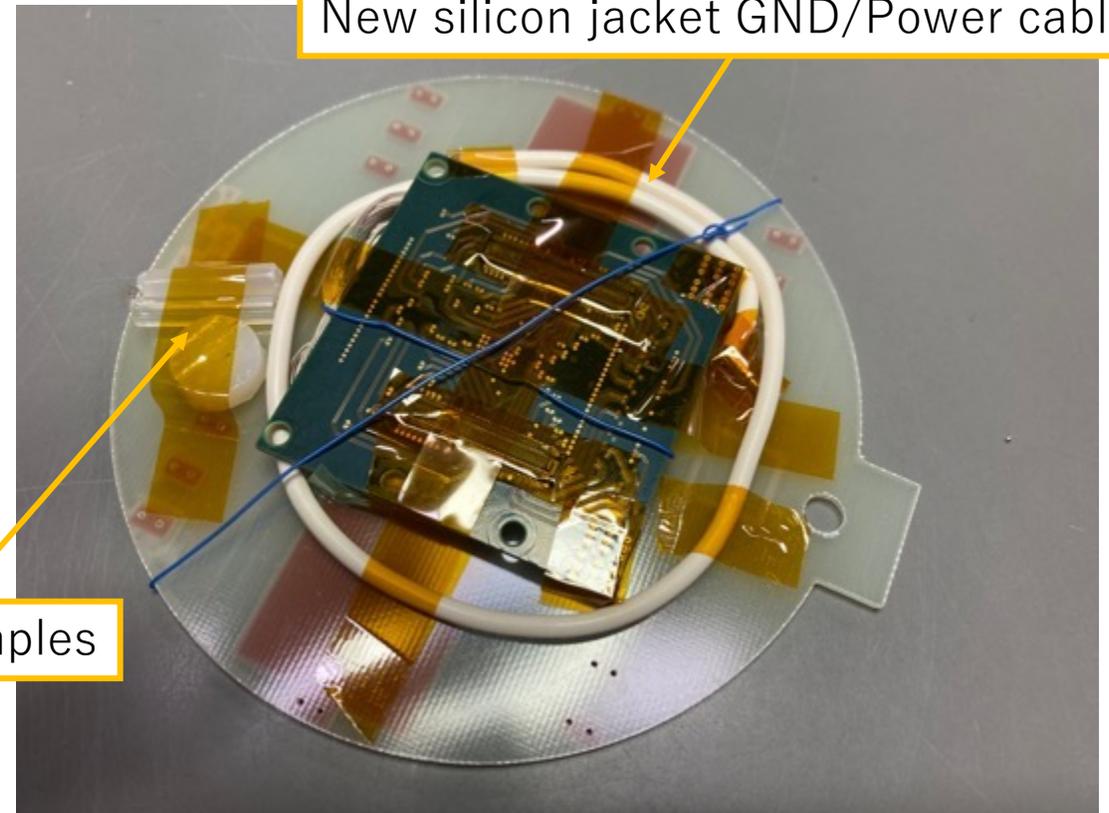


PFA Samples

μ-Coax Cable

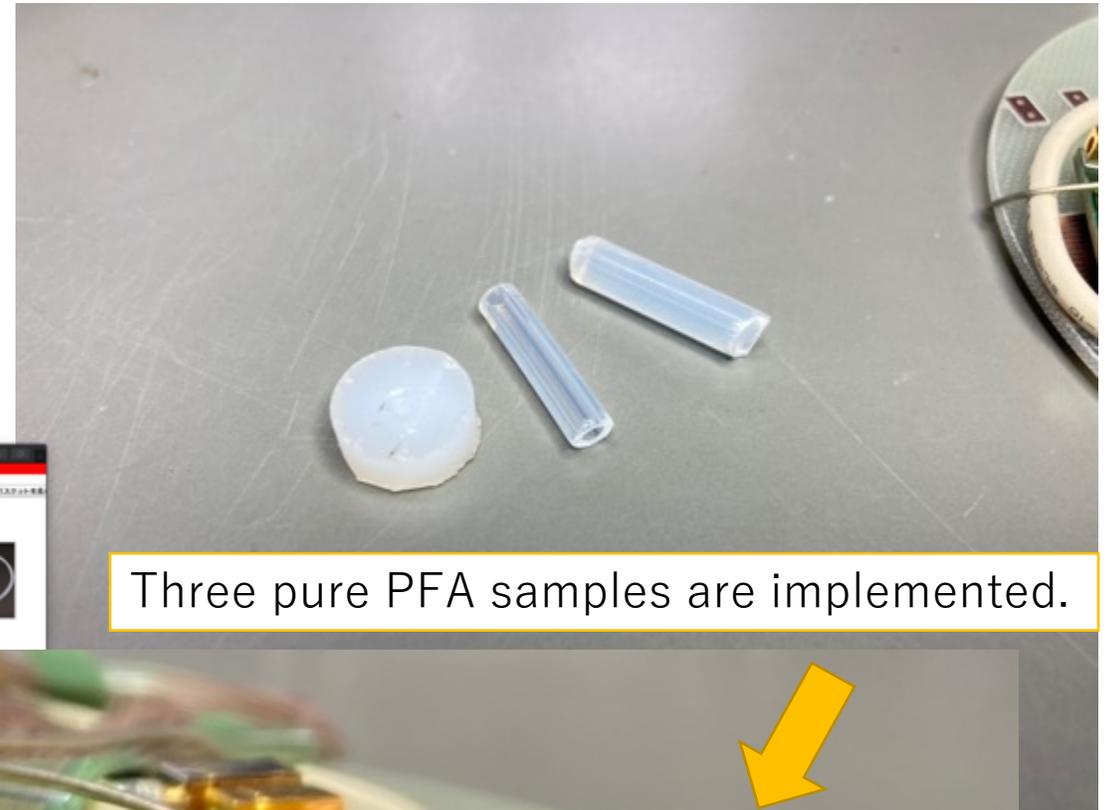
Attached to the disk (Front View)

New silicon jacket GND/Power cable



Attached to the disk (Back View)

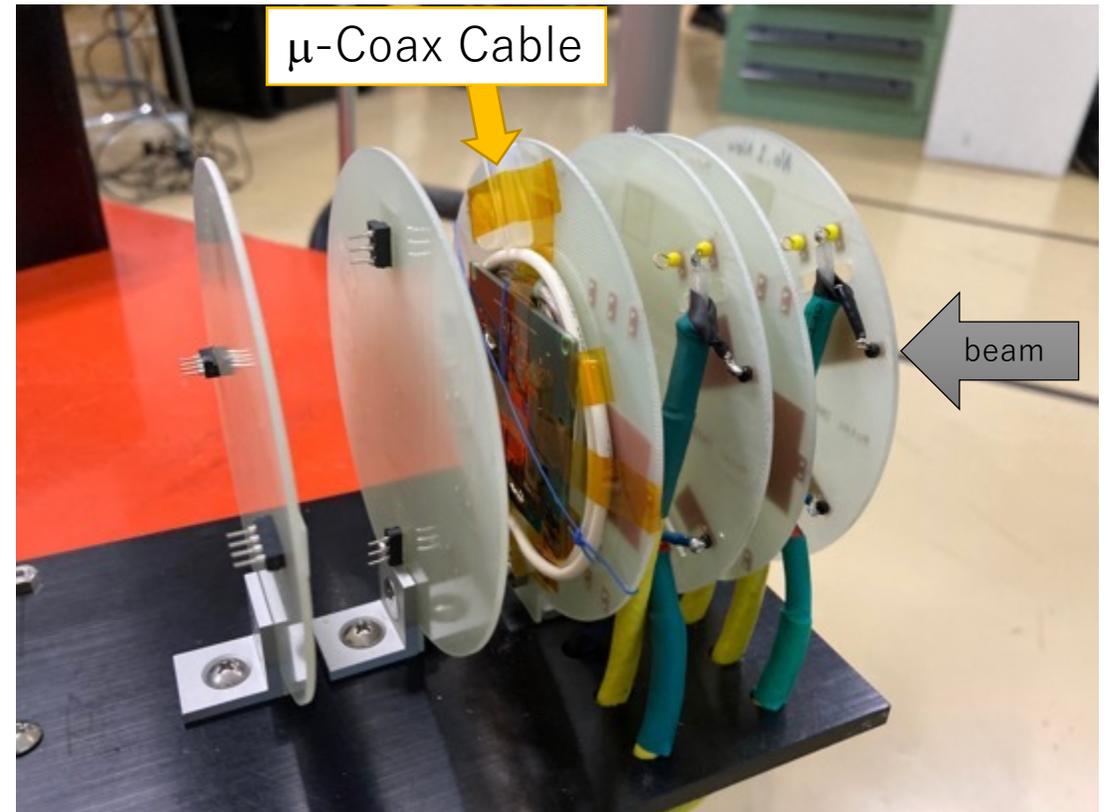
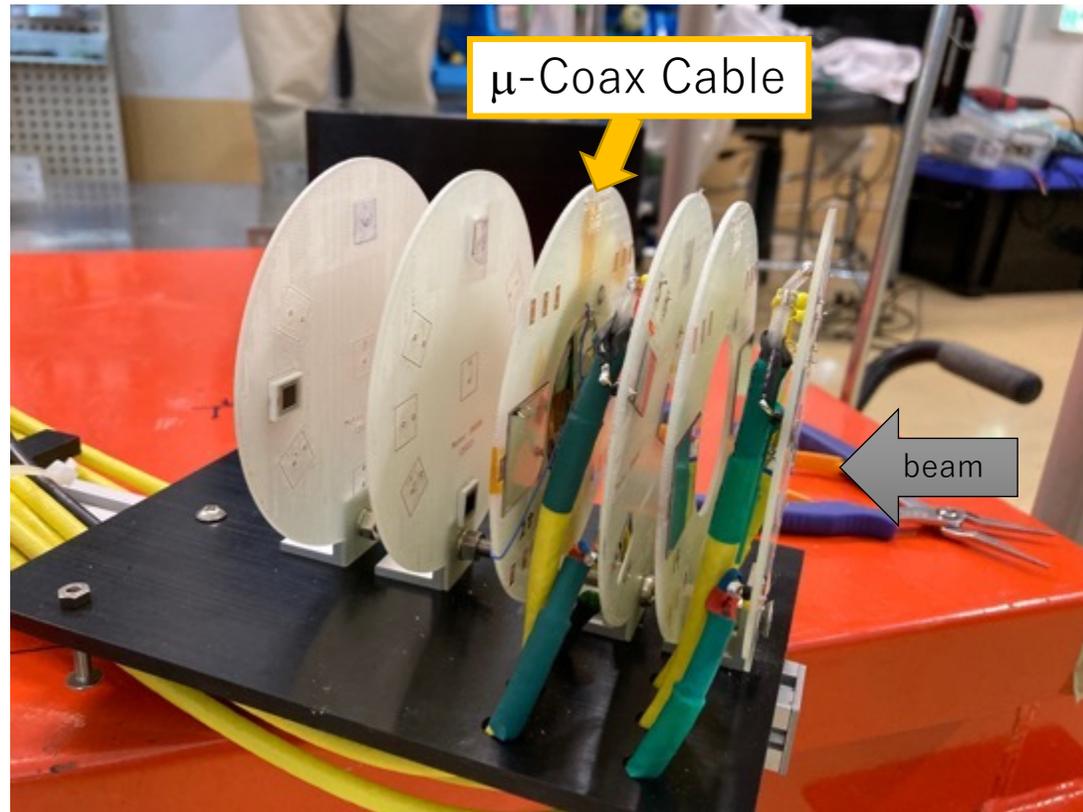
PFA Samples



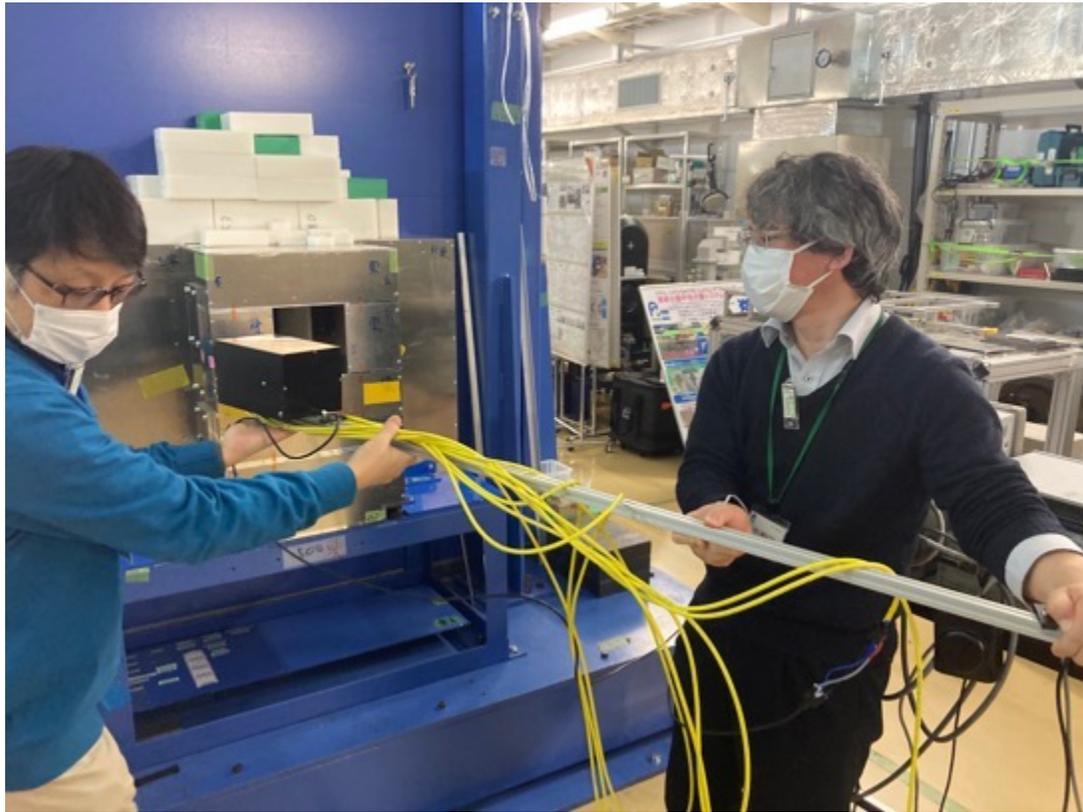
Three pure PFA samples are implemented.



Disk Mount Setup with FoCAL Sensors



Installation to neutron source vessel

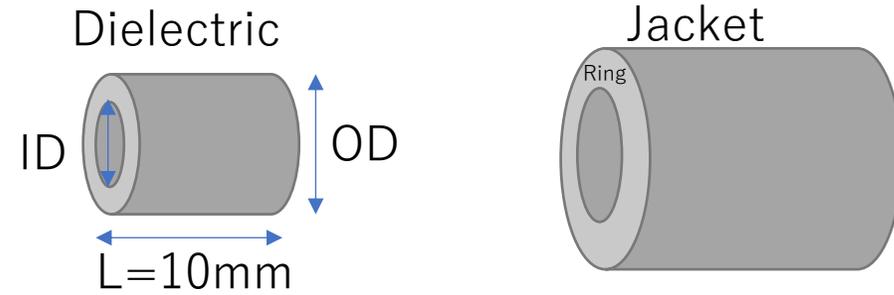


μ -Coax PFA Volume

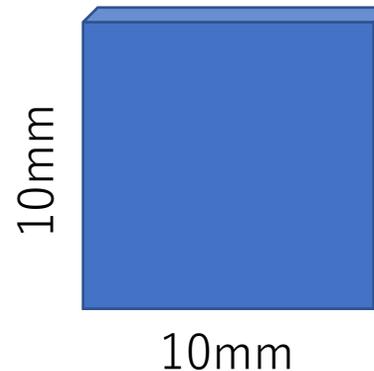
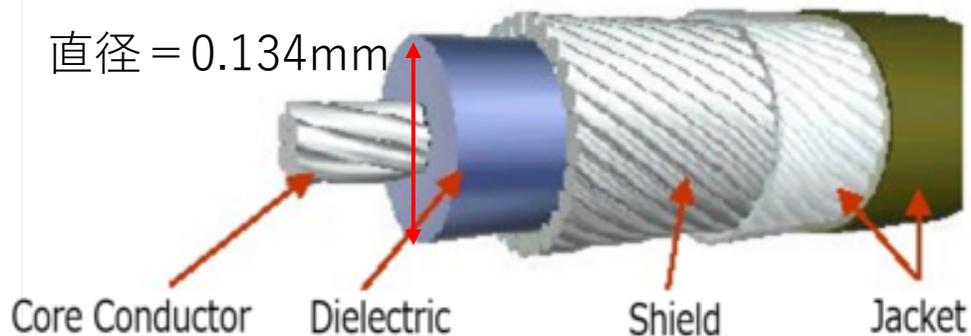
Material Breakdown of micro-Coax

2. Construction and material

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
	Color	-
Jacket	Material	PFA
	Thick.(nom.)	mm
	Dia. (Max.)	mm
	Color	-

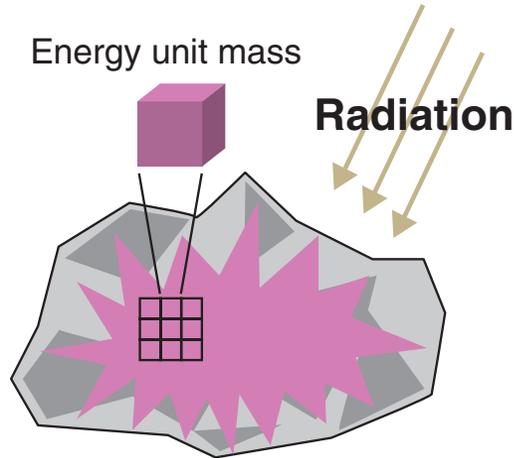


	OD [mm]	ID [mm]	Ring Area [mm ²]	Tube Volume [mm ³]
Dielectric	0.134	0.06	0.011	0.11
Jacket	0.22	0.17	0.015	0.15
Total				0.27



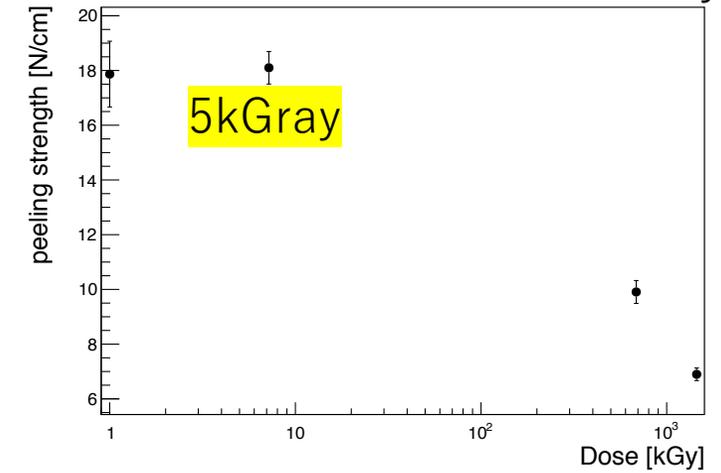
- The volume of PFA per 1 micro-Coax cable: 0.72 [mm³]
- Shape transform for the simulation as a board. The thickness of 10mm x 10mm board is 0.0027mm=2.7 μ m equivalent.

Estimated Radiation Dose



Gray (Gy)

This unit represents how much energy was received by an object or person hit by radiation.
 A dose of 1 gray corresponds to 1 joule of energy absorbed by 1 kilogram of matter.



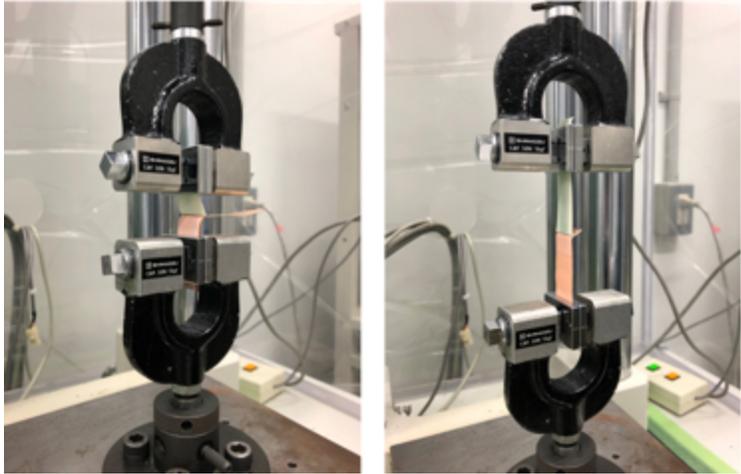
Weight of the Sample to be exposed [mg]	23
Neutron Flux [/cm ² /s]	1E+7
Energy loss per neutron [MeV]	2.7e-6*
Energy loss per neutron [Jule]	8.0E-19
Absorbed dose per neutron [J/Kgm ² =Gy/cm ²]	1.74E-4
Total dose in 10 hours of exposure /cable [Gy/cm ²]	0.6

*PHITS simulation by Genki.

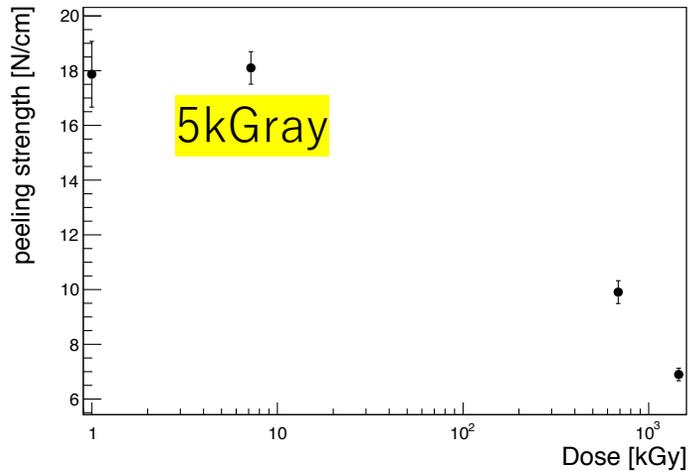
- The estimated radiation dose is predicted to be quite small due to its small volume.
- Presumably, neutron flux is rather important to prove radiation hardness of μ -coax.

Is 60kGray Sufficient?

Hikaru Imai, Deploma Thesis (2021)



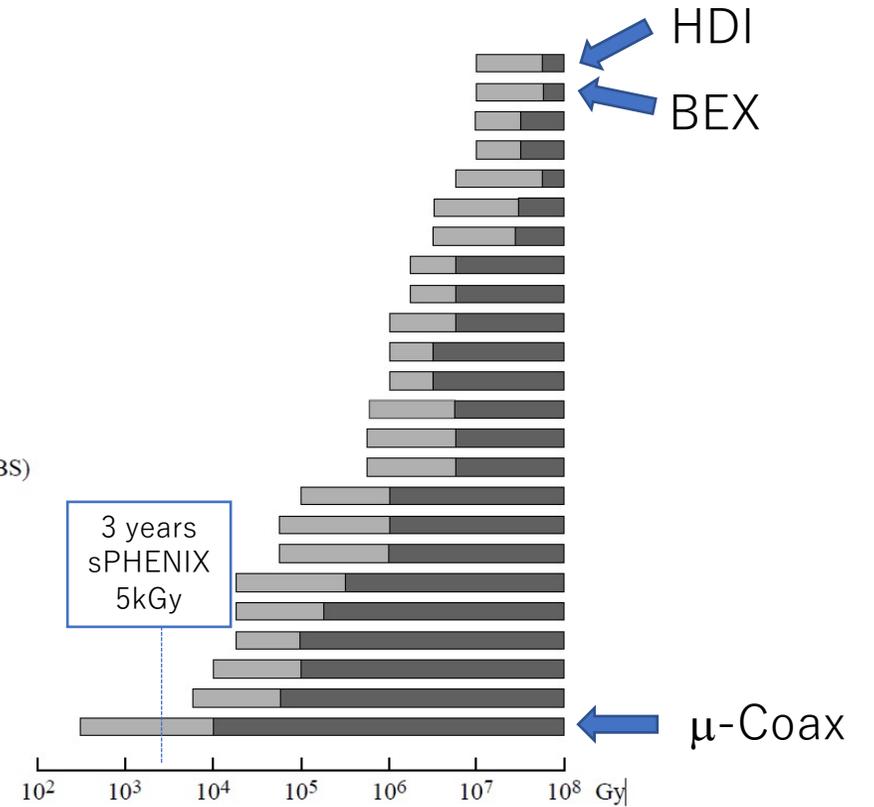
Peel Strength Test



Bus Extender Radiation Hardness Study

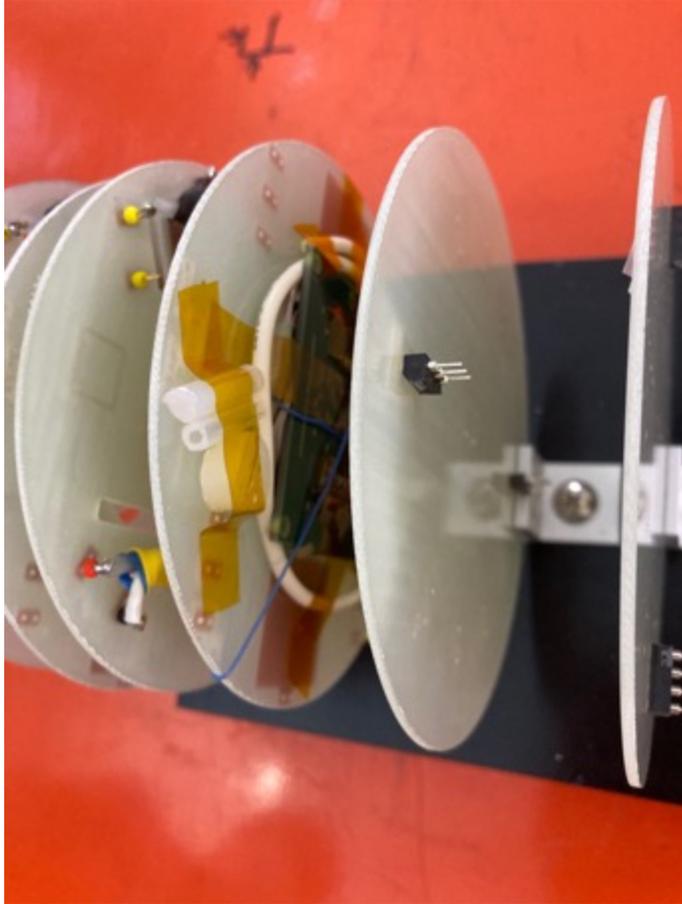
hard ↑

- 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)
- Acylonitrile-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

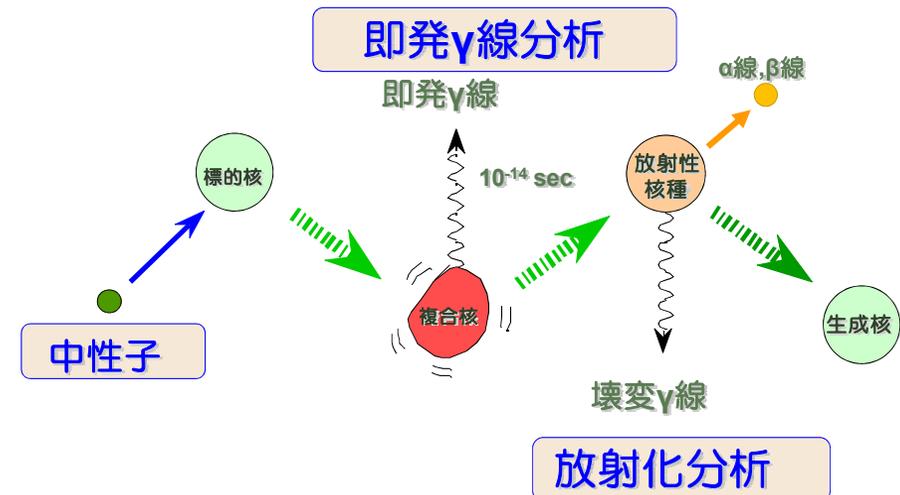
Given the distance of the conversion cable from IP, 60kGray seems sufficient.



Backup

Absolute Radiation Dose Measurement

Indium sample will be implemented right next to the coax-cable.



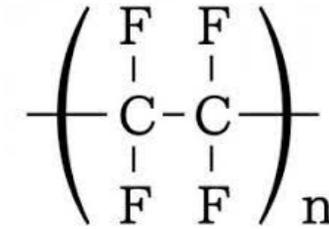
https://www.htc.co.jp/12cyuseishi/kaisetsu/No3_Ref.pdf

The gamma emission will be measured right after the neutron exposure.

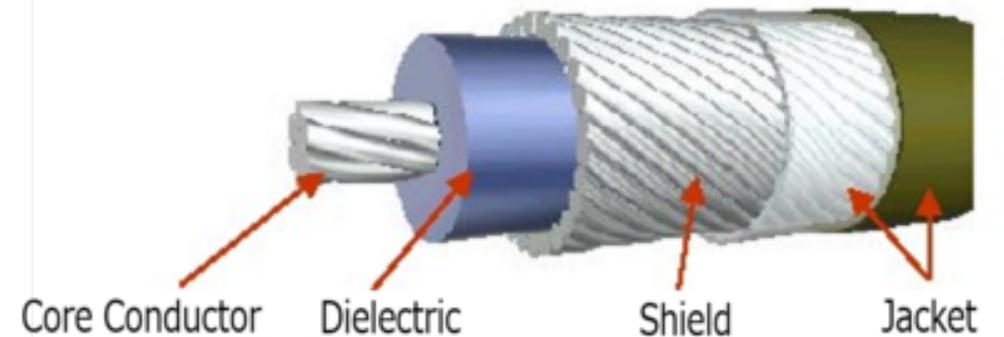
μ-Coax Cable Structure and Material

2. Construction and material Material Breakdown of micro-Coax

Item	Unit	Specified Value
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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	-



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> $\left[\begin{array}{cccc} \text{H} & \text{H} & \text{F} & \text{F} \\ & & & \\ -\text{C} & - & \text{C} & - & \text{C} & - & \text{C}- \\ & & & \\ \text{H} & \text{H} & \text{F} & \text{F} \end{array} \right]_n$

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

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

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 Meinelt, 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.

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 rest 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

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 (AUG) (gamma)
 - 5mm/second (0.412 krad/hr)

Summary

- No discoloration was observed
- No cracking was observed upon bending (1/4" radius)
- Additional radiation did not show any differences in hardness or modulus
- 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.

Additional Dose Testing

Additional Radiation Exposure

Future Work

Summary

Tensile Testing of Insulation Only

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

Additional Dose Testing

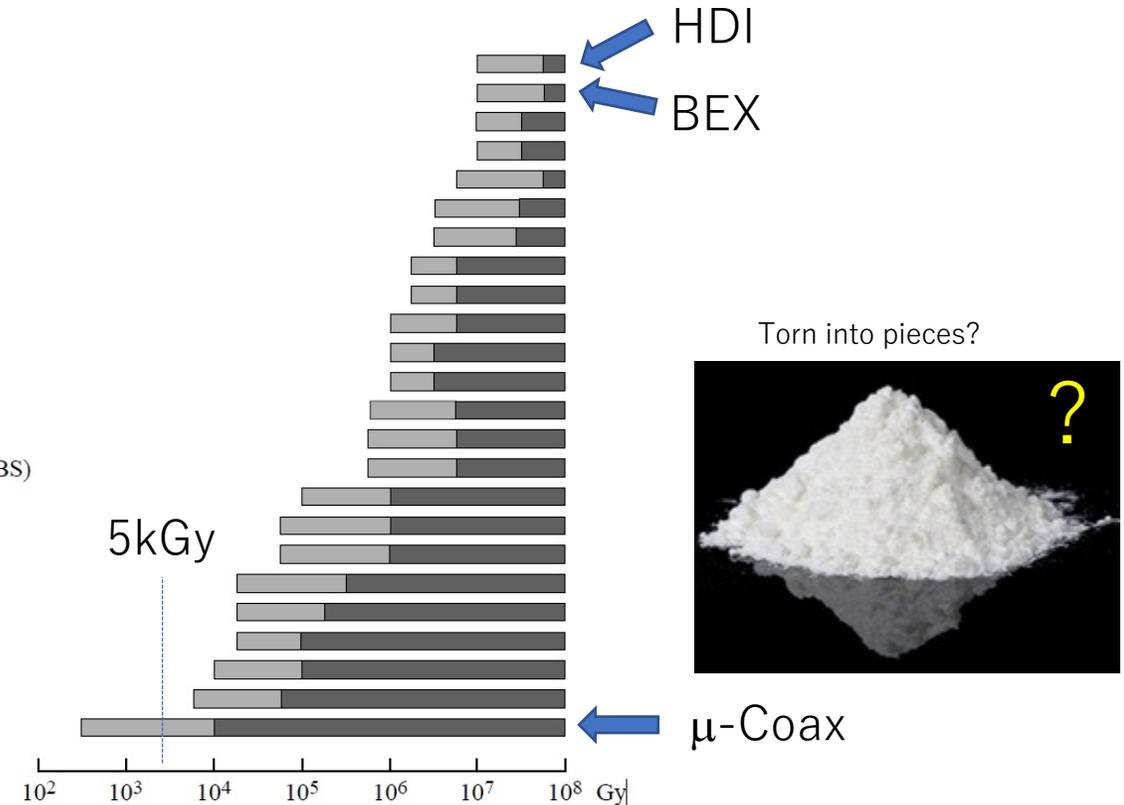
Additional Radiation Exposure

Future Work

Summary

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