Development of Ultra Low Radioactivity Cables and Circuitry

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Q-Flex Inc.

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Q-FLEX INC.

Introducing Q-Flex

- Located in Southern California, we began with only 2 employees in a leased 700 square foot unit in 1998
- Today Q-Flex employs a dedicated staff of highly skilled and trained 26 individuals in a custom built 18,000 square foot facility with a custom 1000 clean room
- Our specialty is flat, flexible, printed cables that are used in a wide variety of applications. Customers include Generac, Medtronic, NASA, JPL, Boeing , SpaceX, Lockheed Martin and many others
- Our motto: *Extremely Difficult We Do All The Time, Impossible Just Takes A Little Longer...*

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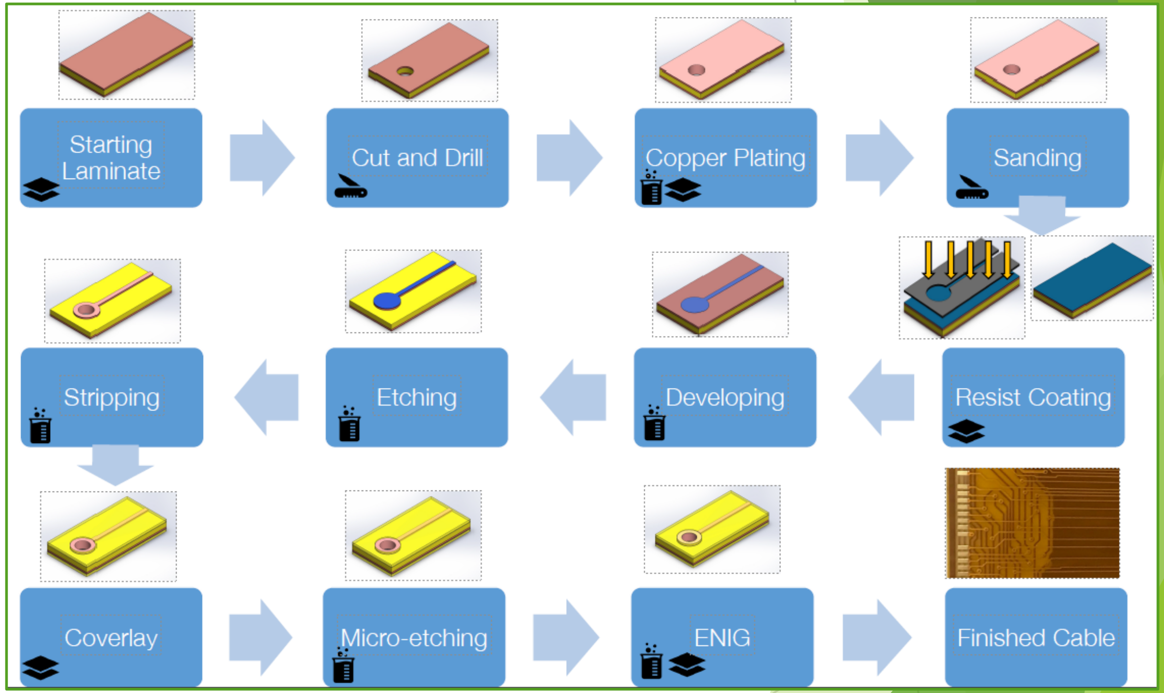
Flexible Printed Cable (FPC) Manufacture

- FPC manufacture is a painstaking multistep process
- Precise fabrication is required to ensure the cable has the desired impedance, conductance, and shielding
- We employ a proprietary process that involves multiple lamination, cutting/drilling, etching, sanding, photolithography and cleaning steps
- The result is a high quality flat and flexible cable that can be used in a wide range of applications



→ **Challenge: make FPC cables that are as "radiopure" as possible**

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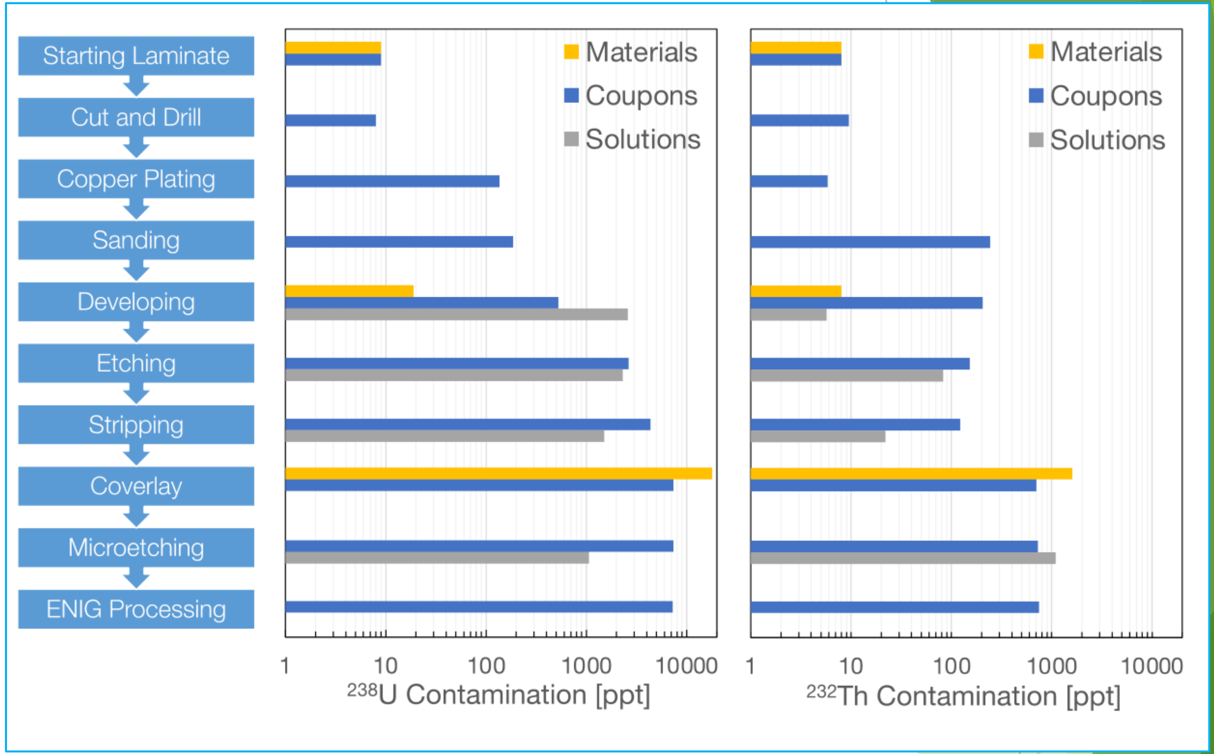
What is Radiopurity?

- There are radioactive contaminants, in particular ^{238}U and ^{232}Th, in virtually everything
- This is especially true of raw materials used in production of flexible cables, including:
  - Copper (conductor)
  - Kapton (coverlay insulator)
- Processing steps used to manufacture/clean cables also introduces contaminants



Initial contamination levels due to FFCC manufacture ~ 7000 ppt ^{238}U and ~700 ppt ^{232}Th…too high!!

Background radioactivity from contaminated materials can distort sensitive measurements or damage sensitive electronic components

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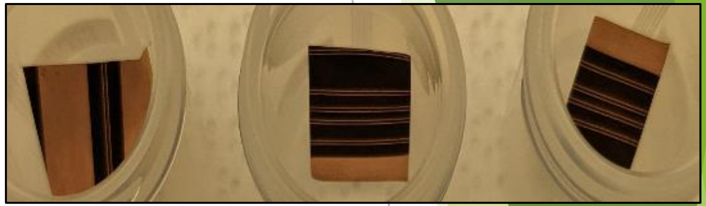
How is RadioPurity Measured?

- ICP-MS (Inductively Coupled Plasma Mass Spectroscopy) allows for ultrasensitive assays of materials, processes, and reagents, reaching sensitivities to uranium (^{238}U) and thorium (^{232}Th) at sub parts-per-trillion (ppt) sensitivities.
- It is the "gold standard" for determining the presence of uranium, thorium, and potassium,
  - These are by far the most serious threat to radiopurity of manufactured components.
- Requires only small samples
- Fast results, allowing for detailed, systematic investigations of a large number of samples

Innovation: Use "Coupons" To Assess RP of Different Manufacturing Steps

- ICP-MS is destructive test, so can't use it on cables themselves
  - Solution: use sheets of "coupons" that undergo same manufacturing process as actual cables, thus are representative of radioactive content in cables
  - Excise samples (< 1 g) from coupons
    - We subsample small portions from the coupons, little "squares" of about 1 cm side
  - dissolve in a concentrated acid solution
  - Inject into ICP-MS for analysis



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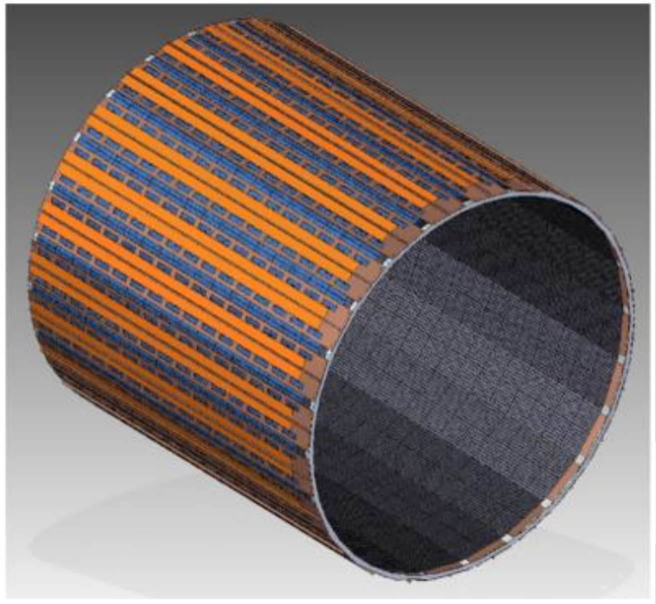
Initial Goal: RP Cables for High Energy Physics Projects

- Example: nEXO, a multiyear project designed to detect searches neutrinoless double beta decay. Experiment requires very low ambient radioactivity to avoid false positive detection
- Other physics projects such as LEGEND, NEXT, OSCURA, DAMIC, SuperCDMS, CUPID and CRESST have similar issues
- Signal sensors and their associated cabling are a significant contributor to background radioactivity
- Solution: RP flexible cables and circuitry that reduce the background from these necessary components



Proposed cable/electronics design for nEXO photosensors [20]. The cylinder shown sits around the active volume of liquid xenon. Photon detectors (shown by the grey rectangles) line the interior cylindrical wall and are instrumented by electronics (blue rectangles). The orange strips are flexible flat cables made by QFlex

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DoE Project: Phase I (2022 – 2023) DE-SC0021547

Goals:

- Approach: Start Pure, Stay Pure!
  - Identify the source(s) of contamination in raw materials and during the cable fabrication process
  - Investigate methods to reduce the contamination
- Evaluate the feasibility of producing ultra-low radioactivity flexible cables and circuitry.

Results:

1) identified the key sources of contamination
2) reduced the U and Th backgrounds to the level of ~ 10's of ppt ^{238}U and ^{232}Th
3) demonstrated that coverlays, vias, and ENIG metallization can be added with only small increases to the radiopurity –simplifying the design and layout of low background cables

	^{238}U [ppt]	^{232}Th [ppt]
Commercial Cable	2600 +/- 40	261 +/- 12
Our Cable	31 +/- 2	13 +/- 3

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DoE Project: Phase II Goals

Goals

- Aim I: Demonstrate RP reduction factors of > 4 x and > 1.5 x in 238U and 232Th on top of results already achieved in Phase I
- Aim II: produce a blueprint "best practices" manual for mass manufacturing radiopure cables and circuitry for general use in physics research and commercial applications.
- Aim III: produce first commercial batch of radiopure cables.

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DoE Project: Phase II Task

Use ultrapure water

- Install new overlarge tanks for RP cable manufacture
  - Improved cleaning
  - Allows for longer cable manufacture (up to 78 inches in length)

Other accomplishments:

- Moved the entire process to Q-Flex (no more cleaning at PNNL)
- Demonstrated the fabrication of low radioactivity cables in the new system.
- First commercial sale of cables!!
  - to DAMIC-M dark matter collaboration, significantly reducing their radioactive backgrounds.

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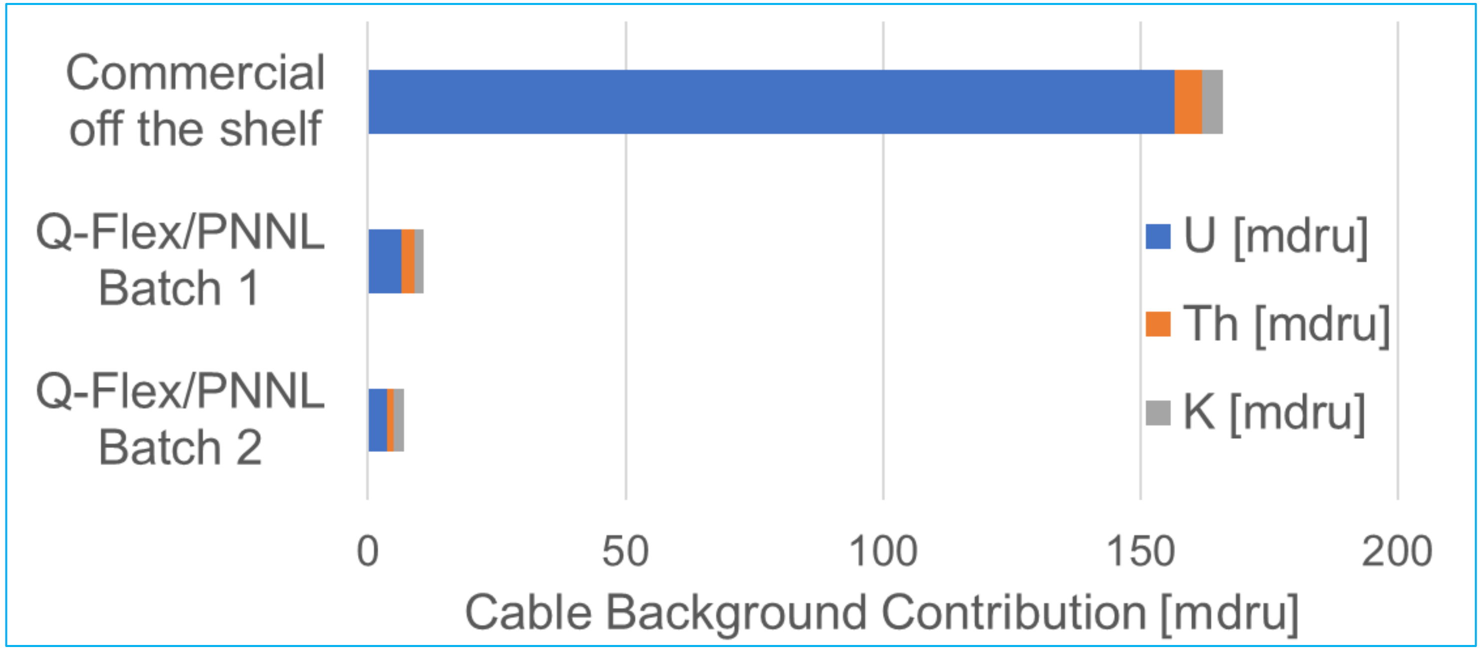
DoE Project: Phase II Results



Lowest radioactive contamination ever achieved on flexible cables

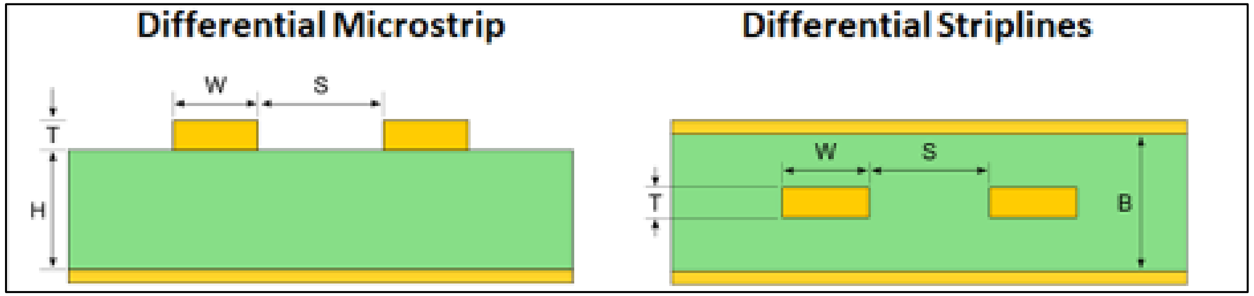
One of the final 28 radiopure cables fabricated for the DAMIC-M dark matter experiment

Principal Results

- Significantly reduced cable RP from Phase I levels
- Delivered 28x 1.5-meter-long flexible cables that met the radiopurity requirements for DAMIC-M

DoE Project: Phase IIB (starting Summer 2025)

- The technical objectives of Phase IIB are:
  - Test a range of commercially available adhesive for use as insulators in the construction of multilayer RP cables
  - Optimize the lamination process used to adhere the acrylics to copper surfaces of a multilayer cable
  - Build the world's first radiopure multilayer stripline cable prototype



Differential Microstrip vs Differential Striplines configurations. The conductive layers are shown in yellow and the insulating layers in green.

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Commercial Applications for RP Cabling

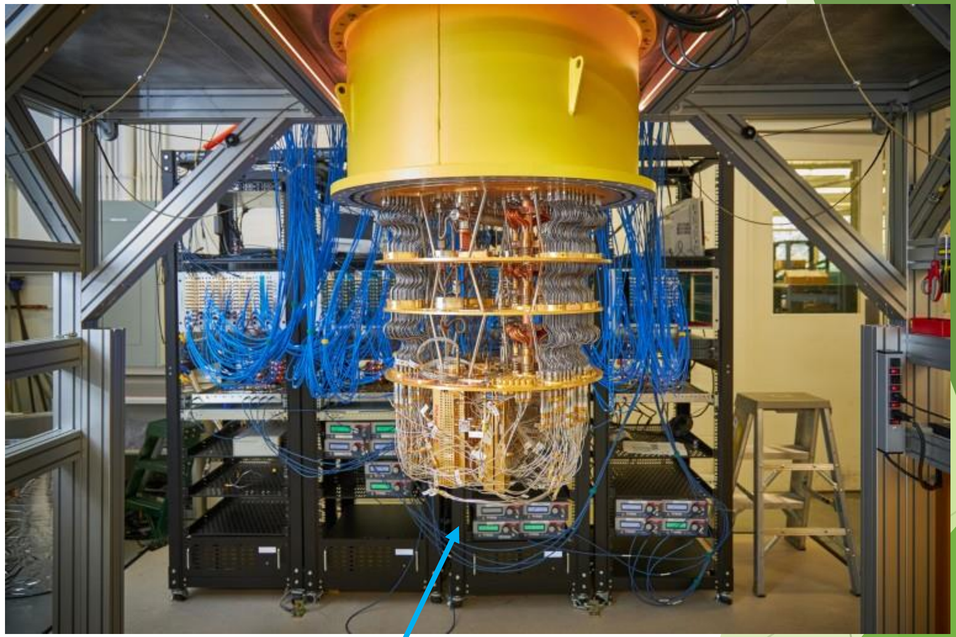
Quantum Computing

- Most QCs require chips to be maintained at ultra low (T < 20 mK) temperatures
- Qubit architecture extremely fragile
- Typical QC has hundreds → thousands of cable connections for I/O
- Space in cold end of QC is at a premium

Ambient background radioactivity is harmful for QC operation for two reasons:

- Heats up the coldest section of DR
- Limits coherence time of qubits→ limits types of operations QC can perform

→ Strong demand for RP flexible cables to maximize QC performance



T < 20 mK when operational

Other Commercial Applications

- Semiconductors
  - ionization caused by energetic particles can change the state of micro-electronics if they strike a sensitive region of the device.
  - cause errors in the device
- Avionics
  - Special class of semiconductors dedicated to for operation on air and spacecraft
  - Ultra sensitive detectors require minimal radiation background to improve SNR
  - Very tight space tolerances, high vibration environment

→ Solution is flat flexible RP cabling

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Thank You!!