Cathode plane material selection

Cathode requirements

- Reasons for resistive cathode:
  - Stored energy in DUNE is sufficient to potentially damage the cryostat membrane
    - The ground plane potentially mitigates this.
  - The voltage swing of the cathode during discharge produces a voltage pulse on the preamps. Simple simulation showed the current in the protection diode is a factor of two less than the diode rating. The resistive cathode reduced this current by orders of magnitude.
- Surface resistivity in the 1 to 100 MOhm/square is required.
- Planarity within 1 cm.

Investigated materials

- MiCarta (“bachelite”)
  - Intrinsic bulk resistivity in the required range
  - Density comparable to LAr
- G10 vetronite coated with resistive layers:
  - ~ Mohm/square ink print with specific patterns
  - Glued bulk resistive kapton foil (25 µm, 6-9 MOhm/cm)
  - Graphite loaded (outer layers) G10

Radiological measurements

- sample: NORPLEX, Micarta, NP 315, phenolic laminate with graphite, black
- weight: 23.0 g
- live time: 328991 s
- detector: GePaolo

- radionuclide concentrations:

- Th-232:
- Ra-228: (15.2 +- 0.5) Bq/kg <==> (3.74 +- 0.13) E-6 g/g
- Th-228 (15.8 +- 0.5) Bq/kg <==> (3.88 +- 0.13) E-6 g/g

- U-238:
- Ra-226 (9.1 +- 0.3) Bq/kg <==> (7.4 +- 0.2) E-7 g/g
- Pa-234m (6 +- 3) Bq/kg <==> (5 +- 2) E-7 g/g

- U-235 < 0.24 Bq/kg <==> < 4.2 E-7 g/g

- K-40: (7.6 +- 0.6) Bq/kg <==> (2.5 +- 0.2) E-4 g/g

- Cs-137 < 50 mBq/kg

- upper limits with k=1.645,
- uncertainties are given with k=1 (approx. 68% CL);

- Ra-228 from Ac-228;
- Th-228 from Pb-212 & Bi-212 & Tl-208;
- Ra-226 from Pb-214 & Bi-214;
- U-235 from U-235 & Ra-226/Pb-214/Bi-214

sample: Current Inc., C770 ESD (Electro-Static Dissipative material), G10/FR4 (glass/epoxy)
weight: 89.0 g
live time: 830876 s
detector: GePaolo

radionuclide concentrations:

Th-232:
Ra-228: (54 +- 8) mBq/kg <==> (13 +- 2) E-8 g/g
Th-228 (49 +- 6) mBq/kg <==> (12 +- 2) E-8 g/g

U-238:
Ra-226 (47 +- 5) mBq/kg <==> (3.8 +- 0.4) E-9 g/g
Pa-234m < 0.52 Bq/kg <==> < 4.2 E-8 g/g

U-235 < 6.9 mBq/kg <==> < 1.2 E-8 g/g

K-40: (4.9 +- 0.3) Bq/kg <==> (1.6 +- 0.1) E-4 g/g

Cs-137 < 3.7 mBq/kg

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);

Ra-228 from Ac-228;
Th-228 from Pb-212 & Bi-212 & Tl-208;
Ra-226 from Pb-214 & Bi-214;
U-235 from U-235 & Ra-226/Pb-214/Bi-214

MiCarta is 50-100 worse w.r.t. G10 for Uranium/Thorium/Potassium… chains

Additional tests

- Resistivity:
  - Discrepancies found depending on measurement method but all measures are within the required range for all materials both at warm and cryogenic temperatures.
- Robustness to sparks:
  - Sparks arising much above the design value of 20 kV/cm both in air (>40 kV) and LAr (> 55 kV)
  - Spark development depends on coating structure/symmetry but are always localized with in few cm radius
  - Micarta slightly more robust (local carbonization visible on kapton/ink after several hundreds sparks).

Proposed baseline option for CPA

- Sandwich of thin G10 foils with resistive coating mounted on G10 bar frame:
  - Total thickness ~1 cm seems feasible.
  - Coating choice can be defined
  - Density larger that LAr eases suspension and planarity
- Resistive outer frame:
  - subject to the highest local fields
  - G10 round bars: resistive coating to be carefully studied.

Material choice

- G-10 preferred over MiCarta.
- Advantages:
  - Lower radiological
  - Denser than LAr (CPA will not float)
  - Stronger than MiCarta
  - Cheap
  - Cathode inner frame does not need to be resistive.

Issues

- Stability of coating on G10 support at LAr temperature
- Aging of resistive coating
- Electrical connection to HV distribution bus
- Panel-to-panel electrical connections