Ultra-pure Copper Electroplating for Background Suppression in NEWS-G

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Introduction

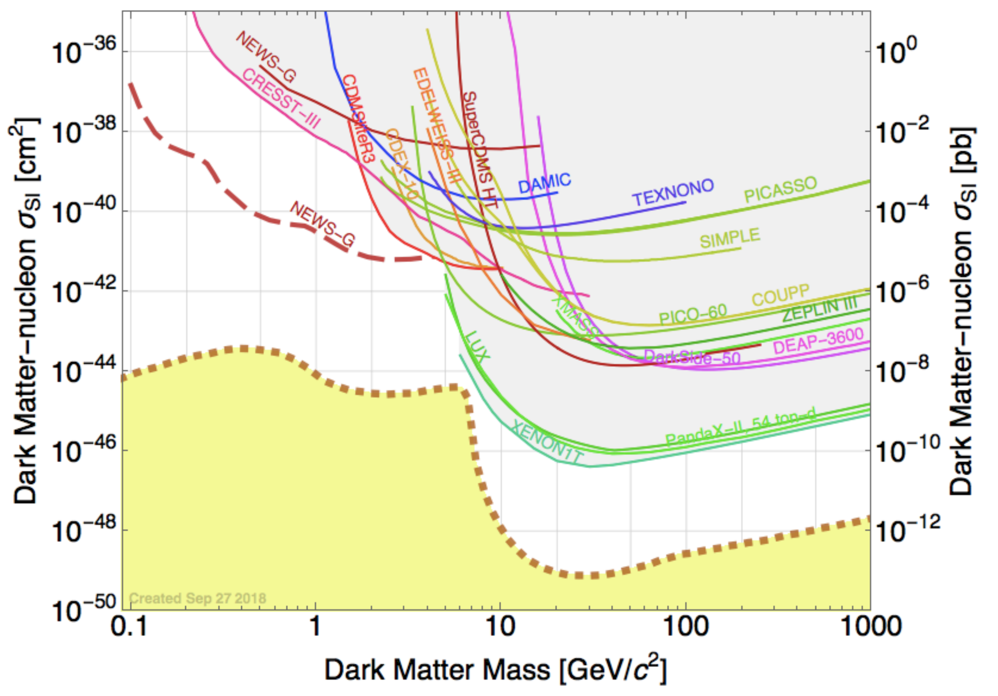


Figure 1: DM cross-section for spin-independent coupling versus the DM candidate mass. Dashed line is the NEWS-G projection. [2]

The absence of conclusive direct evidence for Dark Matter (DM) particles has driven the interest in searches for lower mass candidates, which, due to the requirements of a low mass target and a low energy threshold, remain mostly unexplored, as can be seen in Figure 1.

The New Experiments With Spheres (NEWS-G) collaboration [1] is utilising the Spherical Proportional Counter (SPC) to search for DM in the mass range of 0.1 GeV c^{-2} to a few GeV c^{-2}.

Spherical Proportional Counter

The SPC is a gaseous detector that comprises a grounded spherical metallic vessel with a small, spherical, central anode at high voltage, shown schematically in Figure 2. Electrons produced by ionisation in the detector drift under the influence of the electric field toward the central anode. Within micrometers for the anode, electrons are sufficiently energetic to produce an avalanche giving amplification. NEWS-G are looking for ionisation produced by the elastic scattering of DM particles off the target gas molecules.

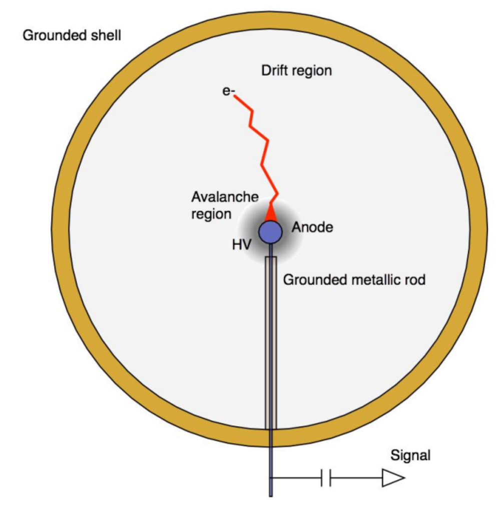


Figure 2: Schematic of the SPC.

NEWS-G@SNO

An SPC, SEDINE, is currently in operation at the Laboratoire Souterrain de Modane (LSM) having produced first results [3]. The next generation of SPC, NEWS-G@SNO, is currently under construction and will improve on the sensitivity of SEDINE.

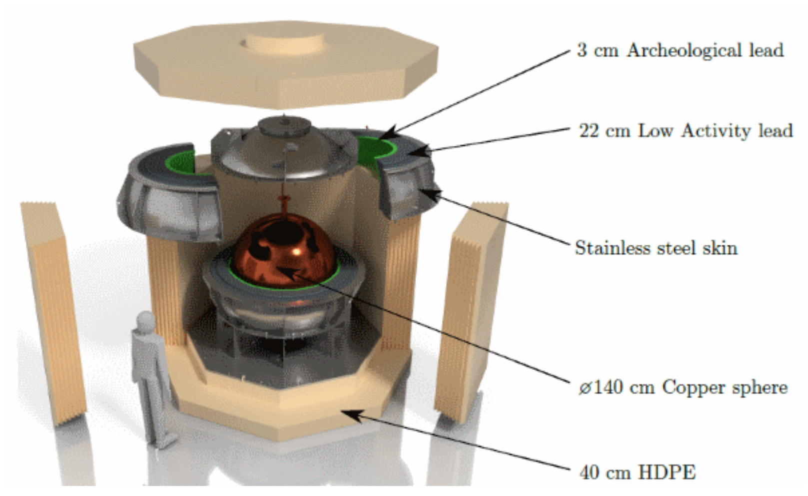


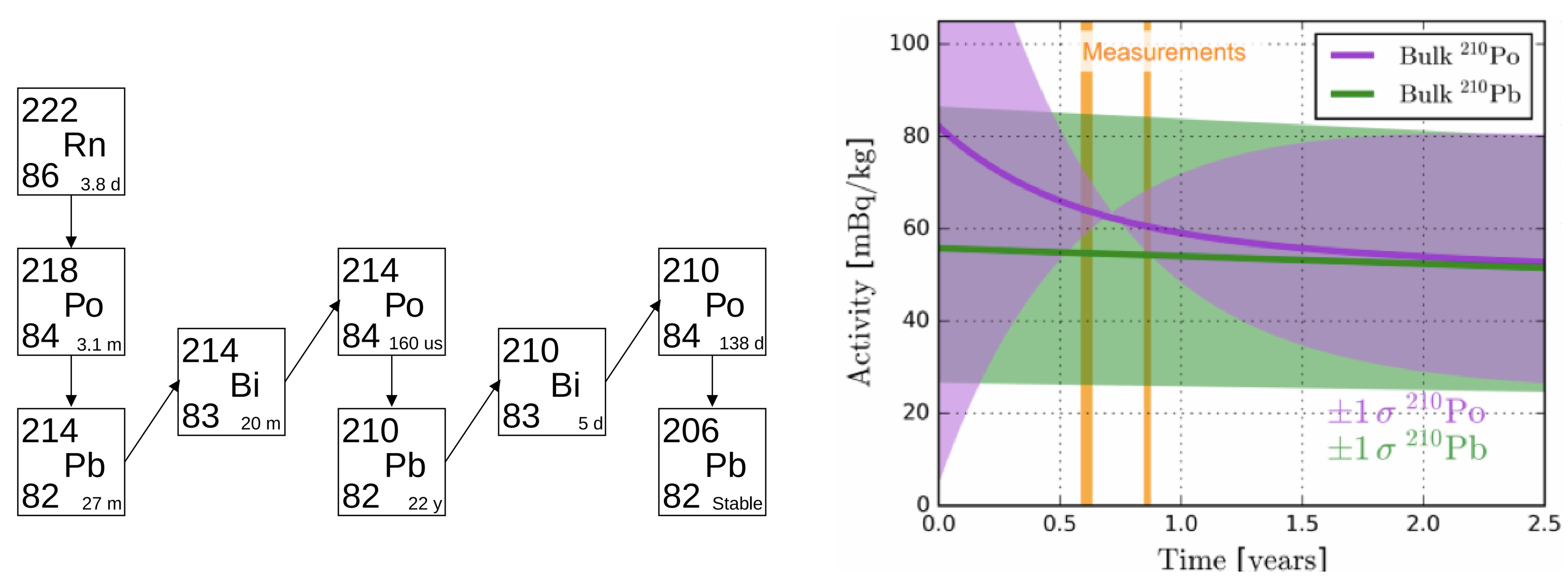
Figure 3: NEWS-G@SNO detector in its shielding.

- 140 cm diameter
- Ne, He and CH_4 gas mixtures
- Operating at up to 2 bar pressure
- Constructed using 4N (99.99% pure) Aurubis copper
- To be installed in SNOLAB, Canada - 6 km water equivalent shielding from cosmic rays

Copper Radiopurity

Copper has no long-lived radioisotopes and most experimental background contributions are from:

- ^{60}Co produced by the ^{63}Cu(n,α)^{60}Co reaction with neutrons from cosmic muon spallation - contributes X rays and β particles
  - Solution: Minimise time copper spends on the surface
- Isotopes from ^{238}U and ^{232}Th decay chains, found naturally in metals and deposited on surfaces by ^{222}Rn gas, with the decay chain shown in Figure 4(a) - contributes X rays, β particles and α particles
  - Solution: Use high purity copper and minimise exposure to air



(a) (b)

Figure 4: (a) ^{222}Rn decay chain and (b) preliminary measurements of ^{210}Pb contamination of copper used.

Commercial copper was found to contain unacceptable levels of ^{210}Pb - inferred from measurements of ^{210}Po [4]. Measurements with the 4N Aurubis copper used for NEWS-G@SNO indicate a preliminary contamination of approximately 60 mBq for ^{210}Pb, as shown in Figure 4(b). The contribution to the experimental background from ^{210}Pb and ^{210}Bi can be reduced by factor of ~ 3 if a 500 µm ultra-pure copper layer is added to the detector surface.

References

[1] https://news-g.org/

[2] Produced using: DMTools, http://dmtools.brown.edu/

[3] Q. Arnaud *et al.* [NEWS-G Collaboration], Astropart. Phys. **97** (2018) 54

[4] K. Abe *et al.* Nucl. Instrum. Methods Phys. Res A **884** (2018) 157

Electroplating Radiopure Copper

An electrolytic cell - schematically shown in Figure 5 - comprises an anode, a cathode and an electrolyte between. In electroplating, electrons are supplied by the cathode allowing positive ions to reduce and deposit on the surface. The opposite process is electropolishing. The mass deposited, M, depends on the current, I, and the time of plating, t, and is given by,

$$M = \frac{m_r \int I \mathrm{d}t}{zF}, \tag{1}$$

with m_r the molecular mass of the ion to be plated, z the number of electrons required to reduce this ion, and F is Faraday's constant.

Reduction reactions are governed by the ion concentration and standard electrode potential (SEP). The cell potential, E^0_{cell}, is defined as the difference between the SEP for the reactions at the anode, E^0_a, and cathode, E^0_c,

$$E^0_{cell} = E^0_c - E^0_a, \tag{2}$$

and reactions will proceed if this is positive or if there is a potential difference between the electrodes that is large enough to drive the reactions. Table 1 shows the SEP of copper compared to other ions and indicates that copper will preferentially reduce at the cathode as it has the least negative SEP. By carefully selecting the electrode potential difference ultra-pure copper may be electroplated. 0.3 V is typically used.

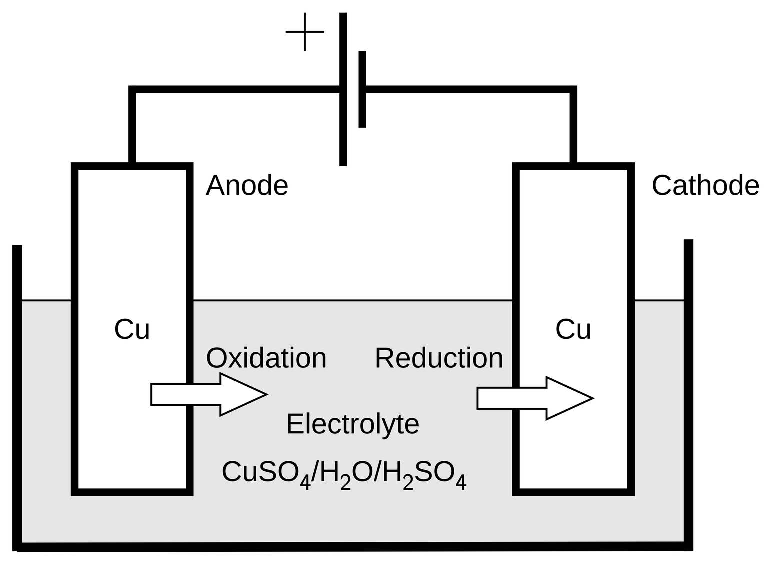


Figure 5: A basic electrolytic cell.

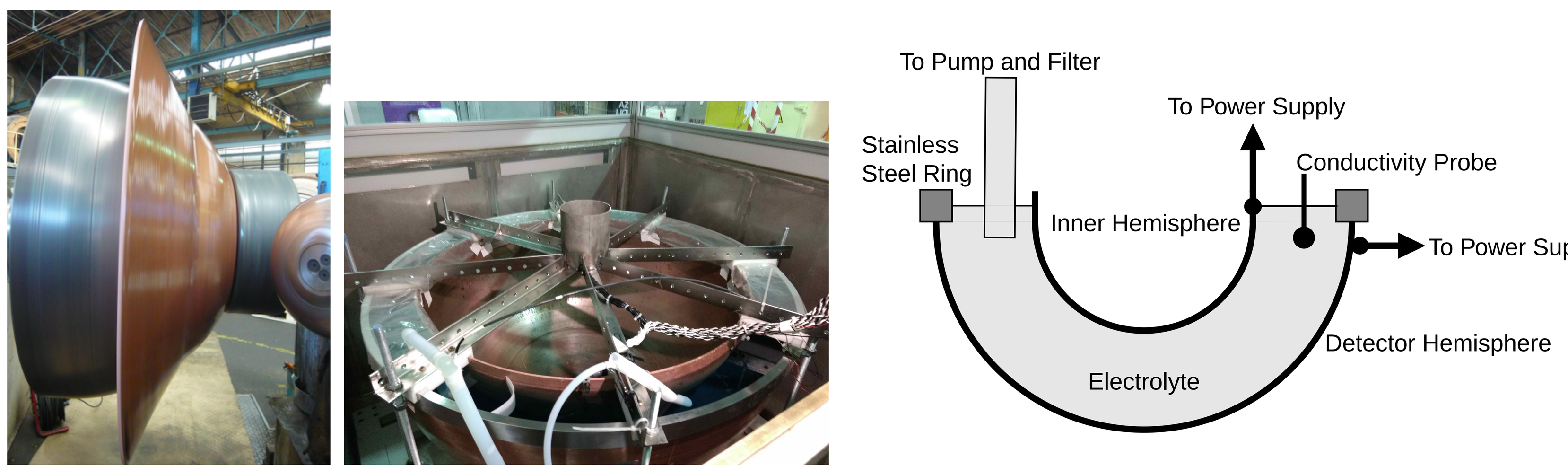
Table 1: Reduction potential of copper and of some contaminants.

Oxidants		Reductants	SEP [V]
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$U^{3+} + 3e^-$	$\rightleftharpoons$	U	-1.80
$Th^{4+} + 4e^-$	$\rightleftharpoons$	Th	-1.90
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	-0.44
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	-0.13

Electroplating Detector Surface

The copper was spun into hemispheres, shown in Fig. 6(a). It was then cleaned, sanded, and subsequently,

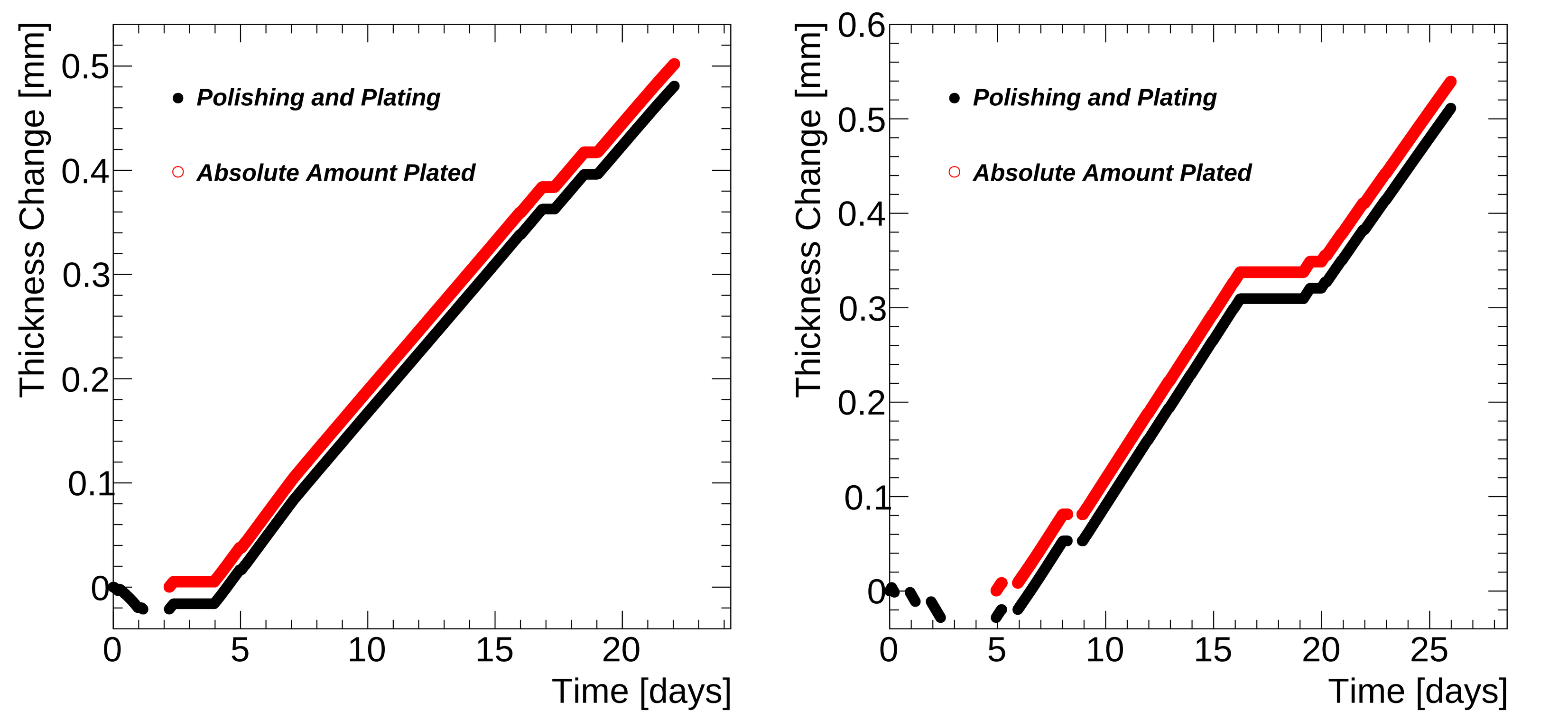
- Chemically etched with acid-catalysed hydrogen peroxide solution
- Installed detector hemisphere, filled with water, copper sulphate and sulphuric acid based electrolyte shown in Fig. 6(b) and 6(c). A smaller hemisphere was used as the anode
- Electropolished surface to remove ~ 25 µm
- Electroplated ~ 500 µm ultra-pure copper onto surface
- Rinsed surface and passivated with 1% citric acid solution



(a) (b) (c)

Figure 6: (a) Detecotor hemispheres being spun from a sheet of copper. Electroplating set-up (b) photograph and (c) schematic.

Electroplating took approximately 15 days per hemisphere with the plated thickness over time shown in Fig. 7. The plating rate was equivalent to 0.036 mm day^{-1} or 1.3 cm year^{-1}. Samples of deposited copper and electrolyte are currently undergoing chemical analysis to verify radiopurity.



(a) (b)

Figure 7: Thickness of copper electroplated as a function of time for (a) the first and (b) the second hemispheres. The initial decrease corresponds to the electropolishing phase and the plateau to shutdowns.

Summary

NEWS-G aims to probe for low-mass DM particles, requiring the minimisation of experimental backgrounds to achieve this. While copper is a standard material, it has been found to be insufficiently radiopure. Electroplating a cladding-type ultra-pure copper layer reduces the background contribution from the underlying material. The technique has been successfully demonstrated on the hemispheres used to construct the NEWS-G@SNO SPC.