VERSATILE DEVICE FOR IN-SITU MULTIPLE COATINGS OF LONG, SMALL DIAMETER TUBES

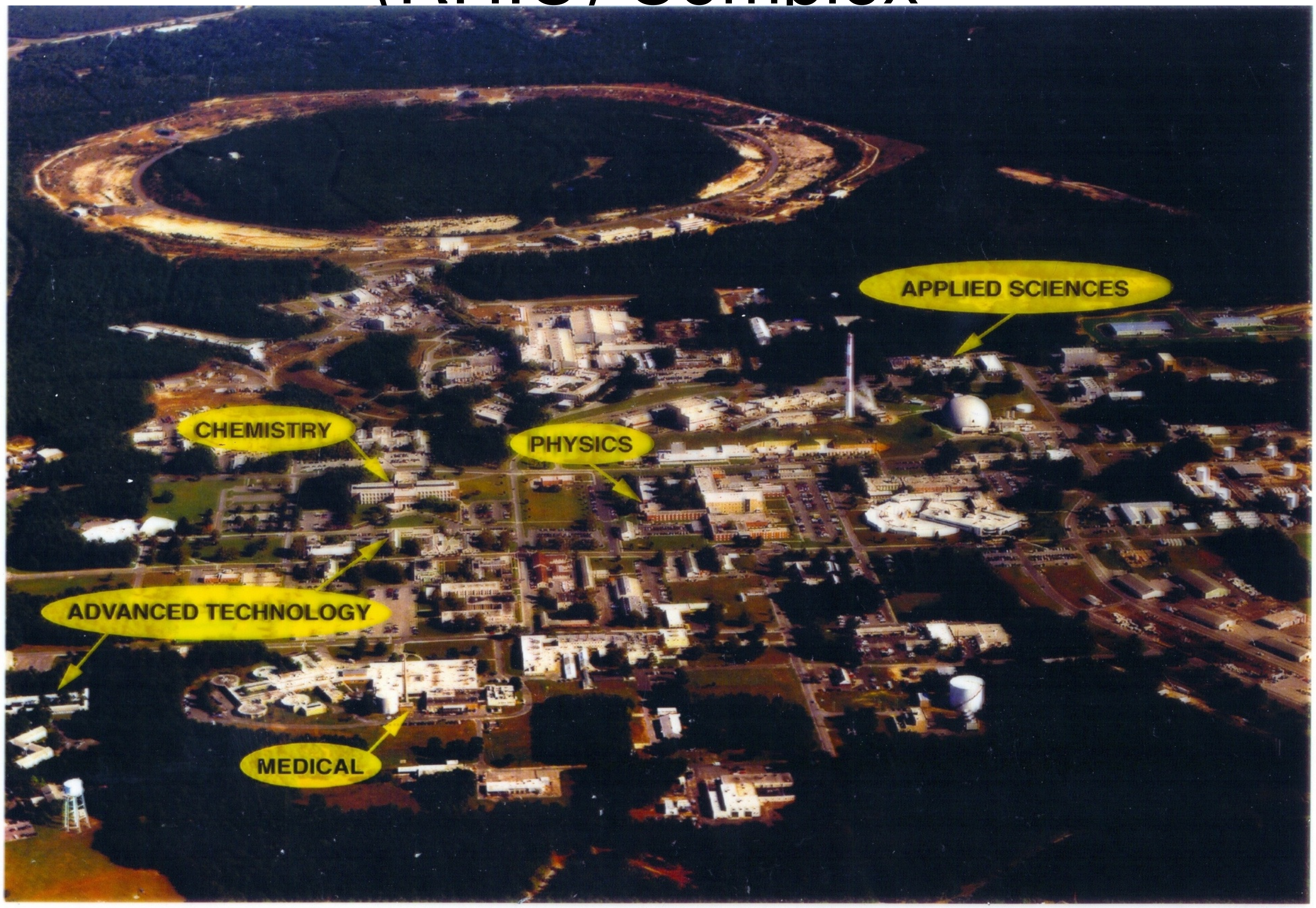
Ady Hershcovitch[1], Michael Blaskiewicz[1], J. Michael Brennan[1], Art Custer[2], Mark Erickson[2], Wolfram Fischer[1], Chong-Jer Liaw[1], Wuzheng Meng[1], H. Joseph Poole[2], Nader Jamshidi[2], Nikolay Sochugov[3], and Robert Todd

1-Brookhaven National Laboratory, Upton, New York, USA

2-PVI, Oxnard, California, USA

3-HCEI, Tomsk, Russia

BNL & its Relativistic Heavy Ion Collider (RHIC) Complex



What problems are needed to be solved in order to enhance RHIC luminosity?

Lower vacuum chamber resistivity and control electron cloud formation!

The RHIC vacuum chamber is made of 7.1 cm ID stainless steel tubing with 1.6 μm surface roughness in cold bore (2.1 μm in warm section). Stainless steel has high resistivity. **Coat tube with copper!**

Electron clouds, which have been observed in many accelerators including RHIC can act to limit machine performance through dynamical instabilities and/or associated vacuum pressure increases. Formation of electron clouds is a result of electrons bouncing back and forth between surfaces, which cause emission of secondary electrons (electron multipacting effect). **a-C coating!**

Possible Solutions

- Coating the stainless steel walls with about 5 micrometers of oxygen free high conductivity copper (OFHC) can prevent problems arising from high resistivity.
- Covering the OFHC with a very thin layer of amorphous graphite to reduce SEY (secondary electron yield)

Coating Long Cold Stainless Steel Tube With OFHC & Other Materials

Development of method involving a moving mole-like plasma deposition sputter device started at PVI Inc. in Oxnard, California, in collaboration with Brookhaven Nation Laboratory (BNL) both in USA, with the end goal for application in 500 meter long sections of the relativistic heavy ion accelerator (RHIC). A copper cathode magnetron sputter device has already generated some experimental results.

DEPOSITION PROCESSES AND OPTIONS

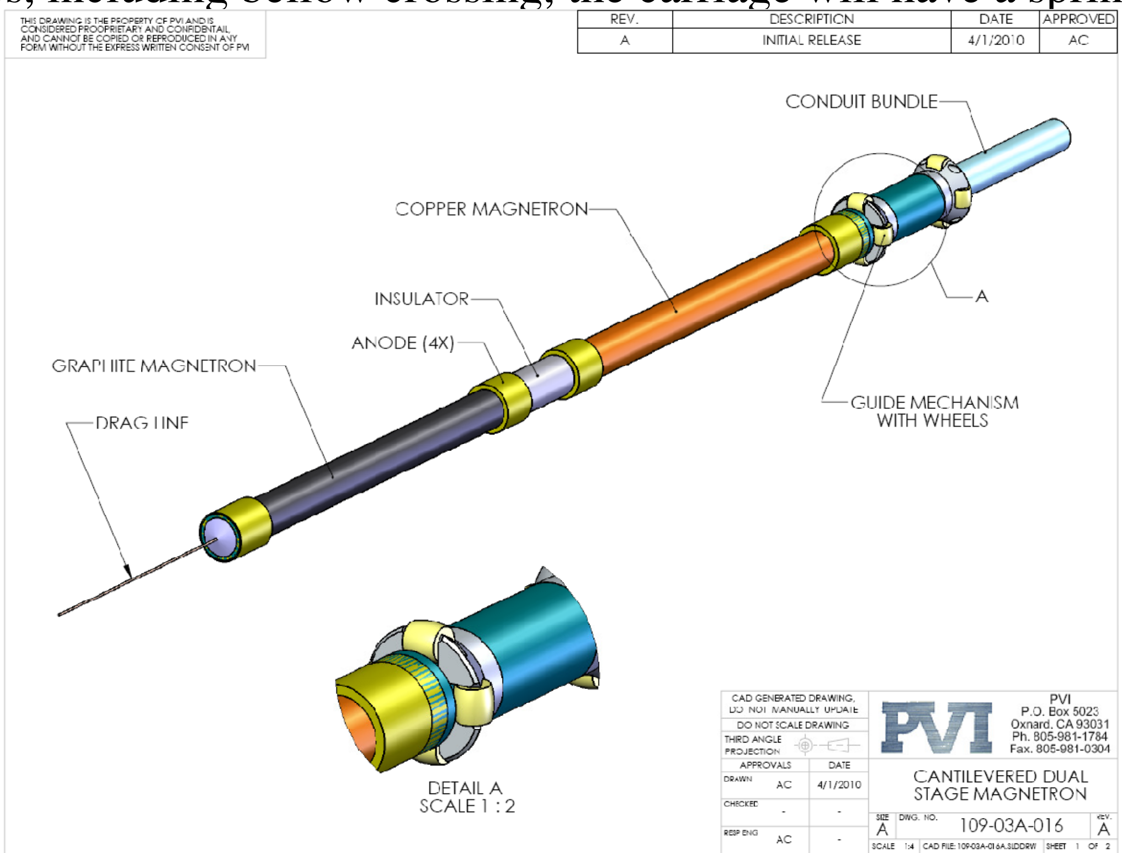
- Coating methods can be divided into two major categories: chemical vapor deposition (CVD) and physical vapor deposition (PVD). Due to the nature of the RHIC configuration, only PVD is viable for in-situ coating of the RHIC vacuum pipes. First, the temperature under which coating can be made cannot be high (400 C is required for some conventional CVD), since the RHIC vacuum tubes are in contact with superconducting magnets, which would be damaged. A second very severe constraint is the long distance between access points. Introduction of vapor from access points that are 500 meters apart into tubes with 7.1 centimeters ID would likely not propagate far and result in extremely non-uniform coating.
- But these constraints also severely restrict PVD options. Obviously evaporation techniques (ovens, e-beams) cannot be used in 7.1 centimeters ID, 500-meter long tubes. Therefore, evaporation must be accomplished locally. One option is a plasma device on a mole that generates and deposits the vapor locally.
- Presently, there are a variety of PVD methods used to deposit coatings on various substrates. By definition, physical vapor deposition entails purely physical processes of evaporating materials. The vapor then condenses on the desired substrate. There is a wide variety of vapor generation techniques ranging from high temperature evaporation to sputter bombardment by electron beams, ion beams and plasma. The latter involves a discharge like RF, glow, or an arc. The long distance between access points and the need to have a mole like deposition device precludes the use of RF plasmas.

MAGNETRON DEPOSITION STATE-OF-THE-ART

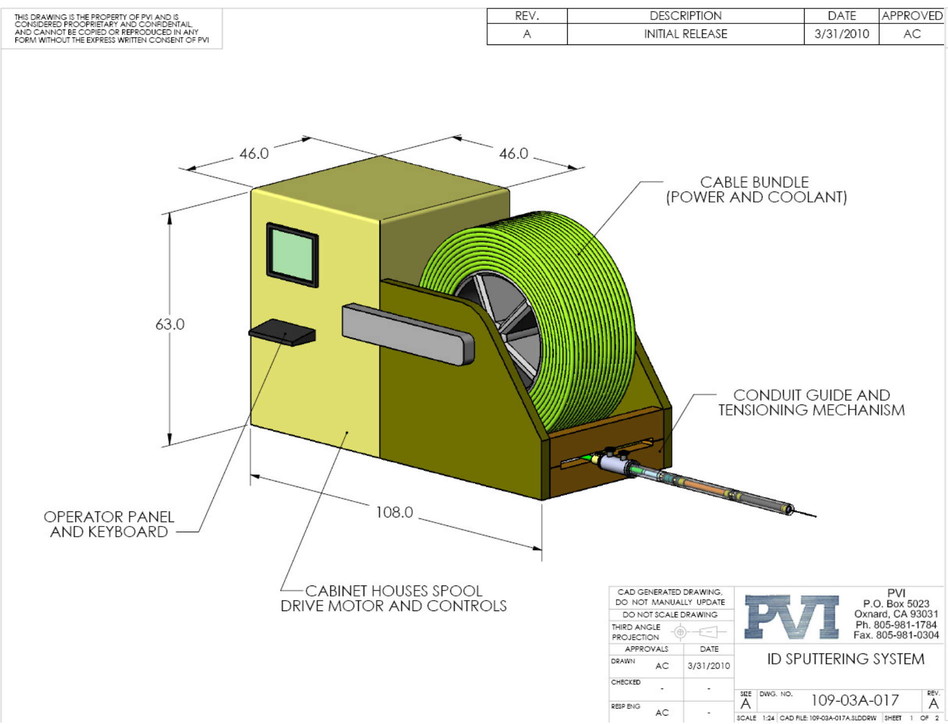
- Of the plasma deposition devices like magnetrons, diodes, triodes, cathodic arcs, etc., magnetrons are the most commonly used plasma deposition devices. In magnetrons, magnetic fields are utilized to confine electrons that generate high density plasma (usually argon or xenon) near the surface of the material that is being sputtered. Major advantages of magnetron sputtering sources are that they are versatile, long-lived, high-rate, large-area, low-temperature vaporization sources that operate at relatively low gas pressure and offer reasonably high sputtering rates as compared to most other sputtering sources. Because of these superior characteristics magnetron sputtering is the most widely used PVD coating technique. Although arc discharges operate with higher intensity, they require the use of special filters to eliminate macroparticles that reduce the net deposition rate to those of magnetrons.
- Typical coating rates by magnetrons (w/argon gas) are 5 Å/sec for a power of 50 W/inch^2 on the magnetron cathode, though with intense cooling cathode power of 100 W/inch^2 is achievable.

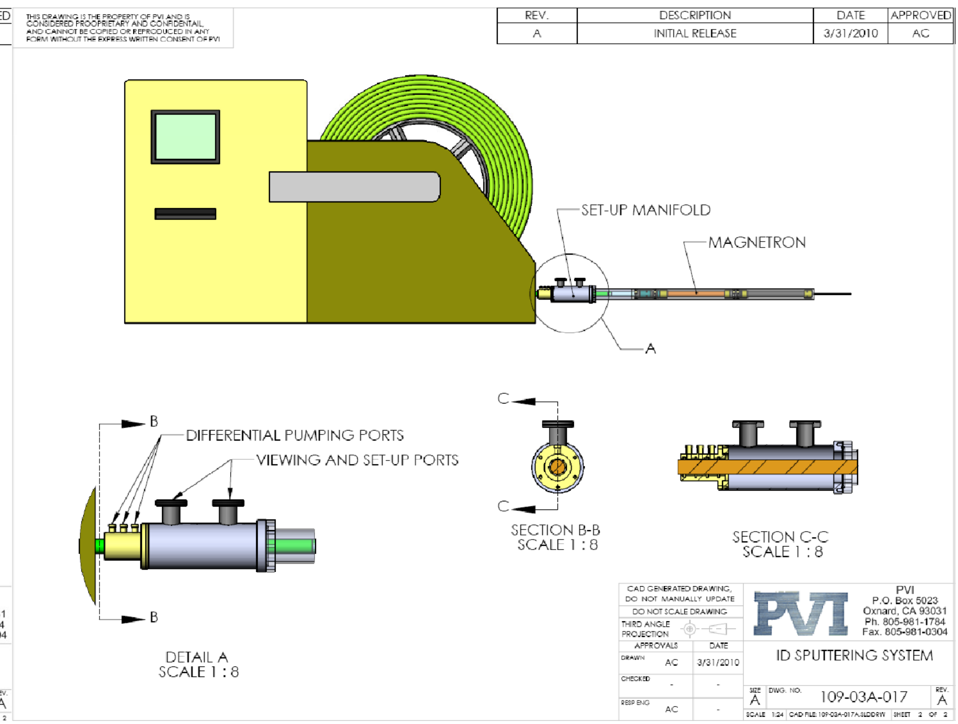
PLANNED DEPOSITION TECHNIQUE

- The ultimate objective is to develop a plasma deposition device for *in-situ* coating of long, small diameter tubes with about 5 μm of Cu following by a coating of about 0.1 μm of a-C. The figure below is a scheme of a plasma deposition technique based on staged magnetrons. Plasma deposition sections consist of two, connected through an insulator, cylindrical magnetron devices. The first magnetron stage has oxygen free high conductivity copper cathode, while the second stage has a graphite cathode. Internal ring permanent magnets form the magnetic field. Magnetron assembly is to be mounted on a carriage (***mole***), which is to be pulled by a cable assembly driven by an external motor. To accommodate for any diameter variances, including bellow crossing, the carriage will have a spring-loaded guide wheel assembly.

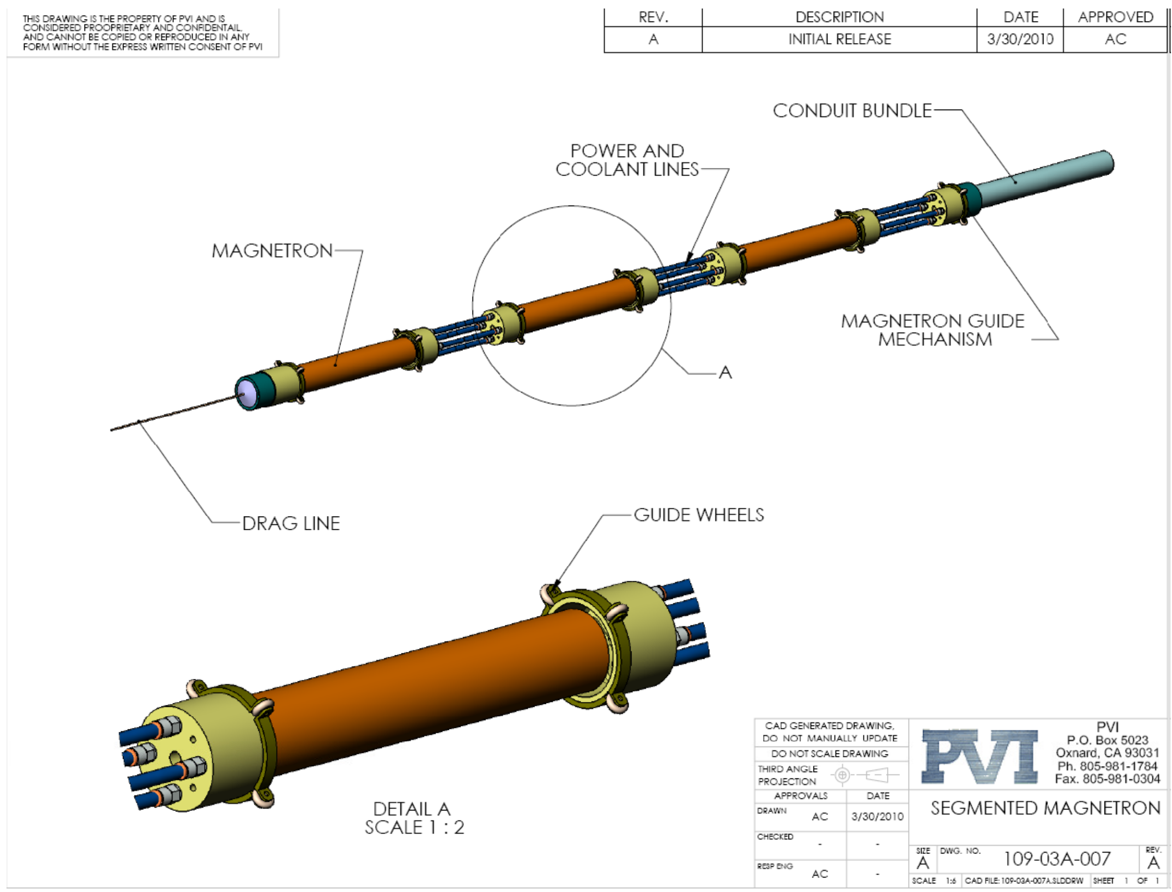


Spool drive mechanism is shown in the below figures. A dragline, attached to end (opposite to the carriage) of the graphite cathode, is used to initially pull the magnetron assembly and cable bundle to the end, where coating begins. The dragline, (also motor driven), is a strong thin cable made of either high-tensile fishing line, or Teflon sleeved Inconel or equivalent. Should there be evidence that either the Teflon or the fishing line live any residue, a pure metal line is to be used. During coating, the magnetron assembly and cable bundle are pulling the dragline (in a direction opposite to, which the dragline pulled on the magnetron assembly and cable bundle). If needed, a brushless DC servo-motor driving 4 rows of internal wheels moves the carriage, which has position feedback, assists carriage motion.

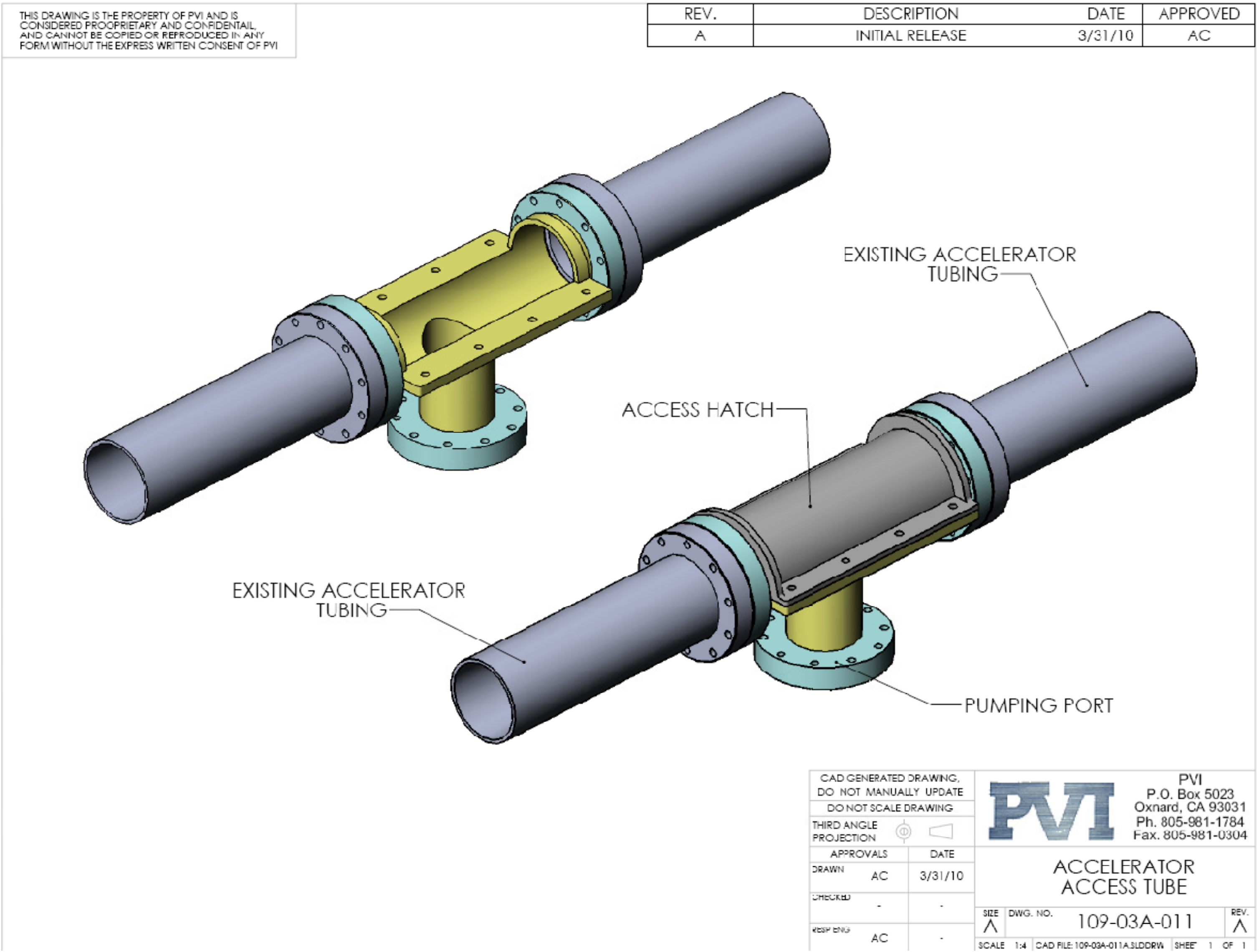




- At a Cu coating rate of 5 Å/sec, it would take 2.78 hours to deposit 5 μm of Cu, i.e., close to 3 hours to move one cathode length. With a 2 meter long cathode it would take 695 hours (or 29 days; a fraction of a typical RHIC shutdown period) to coat 500 m. And 2 m Cu cathode would not need reloading (2.1 meter long cylindrical magnetron cathodes exist in commercial systems). But curvature in the RHIC dipoles would limit single deposition device length to 59 cm.
- Possible solution, if mole support wheels can be employed in areas, which were already copper coated, multiple magnetrons in a train like assembly, having a total exposed cathode length of 2+ meters, as shown below



Worst case scenario, replace some RHIC bellows with access bellows for reloading



EXPERIMENTAL RESULTS

A mobile magnetron, shown below, with a 15 cm long cathode was designed, fabricated, and tested to coat 30 cm long samples of RHIC cold bore tubes with up to 6.1 μm with OFHC at an average coating rate of 30 Å/sec (factor 6 higher than absolutely needed). Copper deposition rates were measured with a 6 MHz crystal rate monitor.

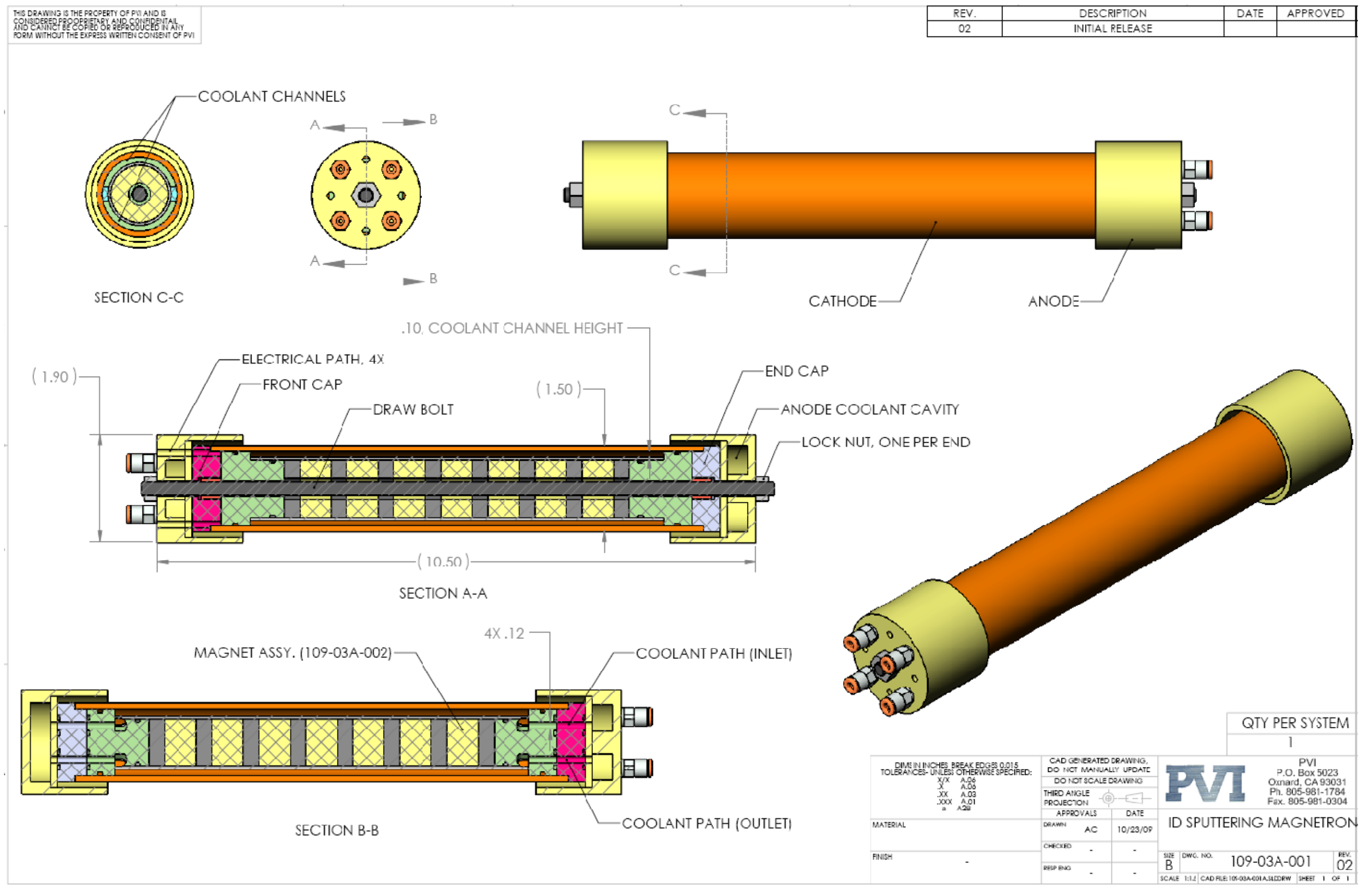
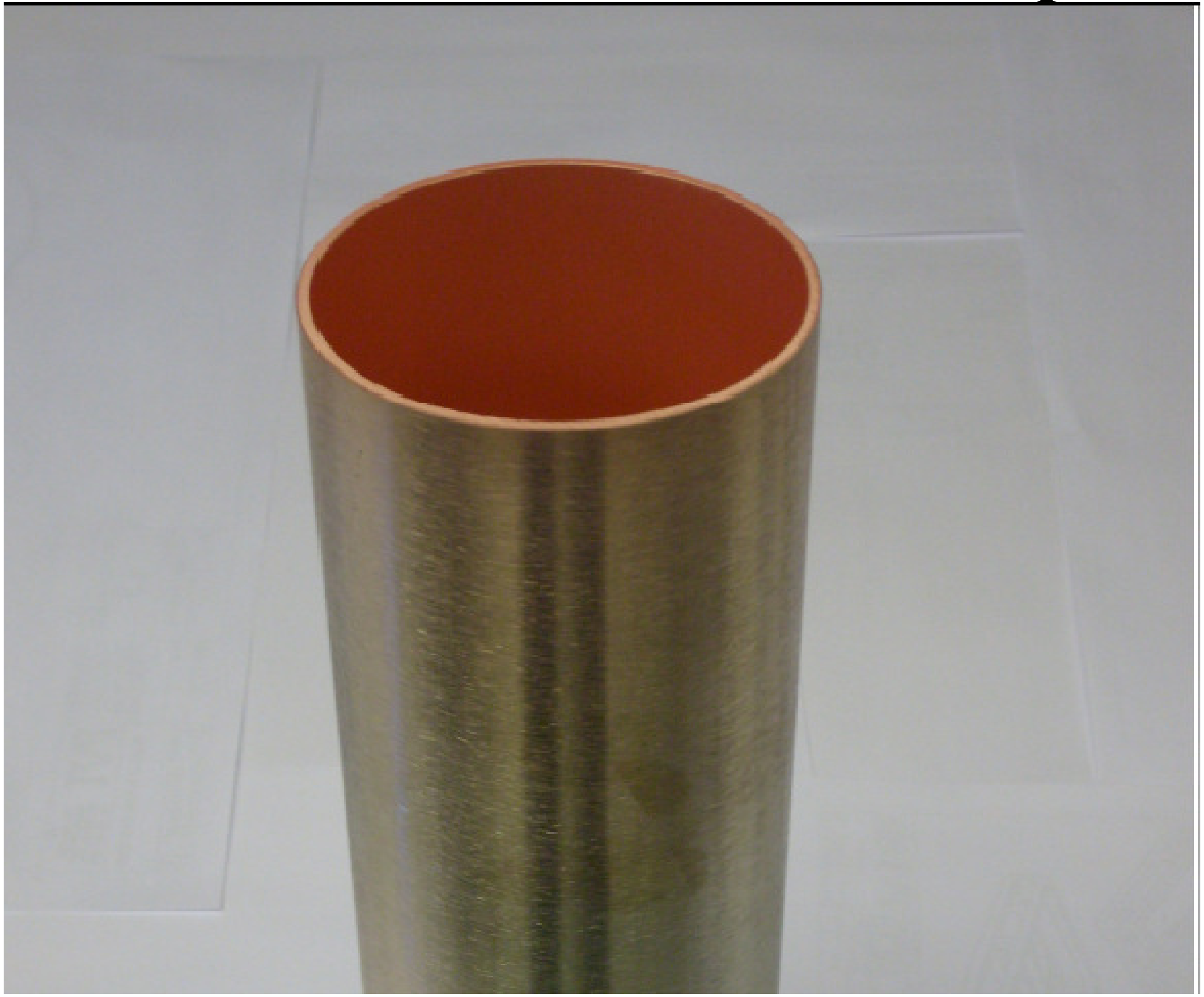


Photo of argon plasma between magnetron surface and tube; power, cooling, and instrumentation feed cables also visible magnetron, plasma discharge and deposition are azimuthally uniform

Photo of copper coated RHIC stainless steel tube sample



Conclusion

A year ago the coating technique seemed feasible, but a number of challenging hurdles were anticipated (PAC09 meeting). Since then experimental copper coating rate was found to be a factor 6 faster! And, solutions were found for engineering issues like cabling and bellow crossing, but other obstacles like limit on device length and possible cathode reloading need appeared. None of the obstacles appear insurmountable, since in worst case scenario, some of RHIC bellows can be replaced with access bellows, as shown in slide 11, to enable cathode reloading.

PVI Thin Film Deposition & Thermal Process Equipment Manufacturer with Vast Experience (in business for over 40 years)

- PVI has designed & built various sizes of batch, load-lock & in-line PVD systems and sputtering sources for various materials.
- Including robotic coating equipment for aircraft canopies where 3-axes robotic manipulators separate robotic assembly that could articulate the canopy resulted in 9-axes of motion combined with conformal shape of the cathodes allowed the aircraft canopies to be coated.

Other Options?

- Silver instead of copper: higher conductivity; can reduce thickness, faster deposition.
- Gold black (amorphous gold) one coating to reduce both resistivity and SEY

Photos of Aircraft Canopy Coating

Coating system layout (right) Plasma discharge sputter operation (left)