

Life with MC-SNICS: ion source development at the Keck Carbon Cycle AMS facility, University of California, Irvine.

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1) Introduction

The Keck Carbon Cycle AMS facility at the University of California, Irvine (UCI), has operated a 40-sample MC-SNICS source (Norton, 1991) since mid-2002. The MC-SNICS sample changer has proven to be a remarkably robust and reliable system: apart from minor sticking problems with plastic actuators in pressure-operated microswitches, it has performed almost flawlessly. In contrast, the ion source itself exhibited several significant problems. These included poor control of Cs within the source; poor serviceability; arcing in the sample wheel and extractor regions; and relatively low negative ion outputs, due in part to poor pumping on the source. The UCI source has been extensively modified to alleviate and in some cases completely solve these problems (Southon and Santos, 2004).

2. Ion source improvements 2002-2004

i) Better control of Cs

The Cs feed tube in the NEC source (Figure 1) is actively heated but has significant clogging problems due to the small bore of the feed tube and the presence of a cold spot where the lower end of the assembly is supported from the source body. This leads to erratic ion source operation, and to shorting out of insulators when the feed assembly is overheated in an effort to break through the plug and "burps" excess Cs into the source.

A new feed based on the very reliable LLNL design (Southon and Robert, 2000) was built into a new ion source body installed at UCI in December 2003. The double-walled feed tube is vacuum insulated over its entire length. The large-bore inner tube screws on to a hollow Cs feed stud in the ionizer assembly (Figure 2), and this firm connection heats the feed tube by conduction – no power supply is needed. The entire oven/tube assembly unscrews by hand for easy servicing after compression is removed from a cooled O-ring joint where the outer tube enters the source body. The solution to a clearance problem between the Cs feed and the heater lead in the ionizer assembly was supplied by Mark Roberts, WHOI (pers. comm.): the ionizer was rotated 120° and a new feedthrough was welded into the downstream source flange (Figure 2).

This change has completely eliminated the clogging problem and dramatically improved the ease of operation of the source, and Cs consumption has been cut by about 50%. The Cs delivery rate is easily varied by adjusting the oven heater and is much more controllable than with the previous system.

The NEC source has no cooling on the downstream end of the source body, and the end flange runs at $>100^{\circ}\text{C}$. UCI's modified source body has a cooling channel in the downstream flange. This traps more stray Cs in the body and reduces buildup in the extraction assembly.

Together, these changes have led to a major reduction in problems caused by stray Cs buildup. In particular, the unshielded insulators of the Cs focus electrode were previously subject to shorting out due to buildup of Cs and sputtered cathode material, and this problem has been completely cured. Arcing in the extractor assembly, due to Cs buildup on the unshielded ceramic rings that form part of the external housing, has also been markedly reduced. We still intend to replace this assembly for improved reliability, but this has become less urgent.

ii) Changes to minimize servicing down time

The standard NEC mounting system for the 40-sample source requires that the entire source and sample changer be disconnected and removed for even routine servicing. We have installed a simple track system based on filing cabinet slides (Figure 3), to allow the sample changer or the entire source to be rolled back in the high voltage rack for easy in-place servicing with electrical, cooling, and pneumatic connections left in place. This modification may seem mundane, but is probably the most important single change we have made to the source. One person can perform a complete source maintenance and have the source outgassed and back online in under 6 hours.

Maintenance is further eased if only one end of the source need be opened for a particular task. In the standard design, both ends of the Cs focus insulators must be accessed to remove and reinstall the Cs focus electrode. Replacing a washer at the downstream end of the insulators with a locknut allows the focus electrode (and the insulators themselves) to be serviced with only the upstream end of the source open. Similarly, a clearance problem between the Cs feed tube, the Cs focus electrode, and the ionizer shield required that both ends of the source be opened to remove the ionizer assembly. Cutting back the Cs focus electrode to improve local pumping (section vi) increased clearances sufficiently that the ionizer can now be removed from downstream with the Cs focus left in place.

Cooling the downstream ion source flange allowed us to use a Viton O-ring for the vacuum seal between the source and extractor. NEC's standard aluminum wire seal had to be replaced every two or three source openings, and installation required careful alignment.

As a part of our extractor redesign (section vi), we removed NEC's upstream extractor collimator, and enlarged the downstream divergence-limiting collimator. This has made the internal alignment of the source far less critical, helping to reduce servicing time. A small stepped-diameter rod that locates the Cs focus aperture relative to the central aperture of the ionizer is the only source alignment tool used routinely. Small misalignments between the ionizer, Cs focus electrode, and sample wheel are compensated for by changing the position of the wheel (typically by .005" or less) based on Cs burn spot patterns. At the 2-4‰ level of precision/accuracy for radiocarbon that

the system now achieves fairly routinely, these small adjustments do not appear to compromise measurement quality.

The Cs oven has been replaced to simplify and speed up Cs replenishment. The new unit is based on a LLNL design (Southon and Roberts, 2000), sealed with a 1.33" Conflat and heated with an inexpensive band heater (Hotset Corp, Battle Creek, MI). It is just large enough to accept full Cs ampoules that are opened under Ar and placed upright in the oven. It is not necessary to heat and pour out the Cs, as with the NEC design. This shorter oven is also less likely to act as a cannon when water is used to clean out residual Cs.

iii) Sample wheel arcing.

A major drawback in operating the standard source is that sparking from the sample wheel is common after wheel changes, and it can take hours before the source will run stably. This problem is due to buildup of insulating oxide and hydroxide coatings on aluminum NEC sample wheels exposed to Cs. Installing a stainless steel faceplate on the wheel improved the contact between the wheel and the spring-loaded cathode voltage feedthrough: this reduced the sparking but did not completely cure it. The area immediately around each sample (which must be left uncovered in a ^{14}C AMS source to avoid sputtering carbon-containing steel from the faceplate) is gradually sputtered into a pit that is difficult to clean. Wire-brushing these areas with a Dremel tool immediately before samples are loaded into a wheel removes the corrosion products from the pits and has eliminated the remaining arcing problems.

We have also developed an alternative solution, which is to use our own UC Irvine designed sample wheels. The new design was implemented to allow us to use larger sample holders that could be labeled to avoid sample mixups, but the stainless steel and copper construction of these wheels avoids the inherent aluminum-Cs incompatibility.

Sparking can still occur when sputtered cathode material buildup on the Cs focus electrode begins to flake off and expose sharp edges, but this is easily avoided by swapping out the electrode every few months during routine source cleaning. The very hard coating is removed by grinding with a diamond-tipped Dremel tool.

iv) Ionizer-extractor arcing.

With NEC's standard conical extraction snout, electric fields between the extractor tip and the downstream side of the ionizer are very strong, and we periodically encountered arcing that we eventually traced to electrons emitted thermionically from the ionizer. The problem was exacerbated by a sharp edge inadvertently left on some ionizer assemblies during manufacturing. We ground back the offending edge, and NEC has modified the ionizer design to remove this problem. We also reduced the electric fields at the ionizer by replacing the extractor snout with a large-bore (1.5" diameter) tube extractor donated by NEC, that we subsequently shortened to increase the extractor gap and further reduce the field. Together, these changes cured the arcing problem.

A second cause of discharges in this region is progressive thinning of the ionizer heater supply and ground return leads over a year or more of hard use. This leads to the

formation of hot spots that eventually reach temperatures where electron emission occurs. The cause is unclear (the Mo wire used is very refractory so evaporation is ruled out) but may be due to sputtering by stray positive ions. The simplest cure is to replace the ionizer assembly, as used ionizers become very brittle and difficult to modify, but we have rescued one assembly by shortening the leads and adding a new length of Mo wire secured to the old stub with a steel sleeve and set screws.

v) Higher output

A key to high output currents is correct positioning of the sample wheel. As other researchers have found (M.Roberts, R.Loger, pers. comm.) running with the wheel several mm back from the factory setting is necessary to obtain a suitably small (~ 1mm) Cs spot at the sample for C⁻ outputs > 100μA.

This shift is required because at high Cs currents, space charge moves the Cs beam waist back several mm further from the ionizer (Southon and Iyer, 1990; Brown et al., 2000). In the NEC source, the Cs focus voltage can be varied to alter the position of the waist, but as Hausladen et al. (2002) have pointed out, when the “focus” lens is run at high voltages it actually defocuses the Cs, pushing the waist back even further. If the lens is run at sufficiently low voltages the waist can indeed be moved closer to the ionizer. However, since the focus voltage also determines the electric field at the ionizer surface and hence the space charge limited Cs current, outputs are severely limited at low voltages. Moving the wheel back allows the lens to be run at high voltages, producing a correctly focused Cs beam at high intensities.

vi) Better vacuum

Experience at LLNL showed that improvements to vacuum consistently gave increased output, presumably due to decreased beam losses through interactions with residual gas.

In an initial modification used previously at University of Arizona (W. Beck, pers. comm.) we cut back the Cs focus electrode “skirt”, leaving a flat plate standing on three narrow legs, to assist local pumping. We have encountered no mounting or alignment problems with the modified electrode.

The standard NEC extraction/einzel lens assembly (Figure 5) severely limits the pumping conductance between the source and downstream vacuum pumps. We rebuilt the internal extractor electrodes with a more open structure, and replaced all aluminum parts with stainless steel for ease of cleaning. The ratio of the pressures at ion gauges mounted on the sample changer bleedup port and below the downstream cryopump dropped by about 50%. This is consistent with an expected doubling of the conductance based on the open area of the new and old designs.

3) Summary

The work done on the UCI ion source has resolved most of the major reliability issues. It

now operates routinely and predictably at outputs of 100-150 μA of C^+ , more than double those initially available when the AMS system was installed. Maintenance has been eased, and turn-on time after a sample wheel change has been reduced from hours to as low as 30 minutes.

These changes can be applied to any 40-sample version of the MC-SNICS source at relatively low cost, using typical university machine shop resources. Modifying the larger 134-sample version of the source may be problematic, due to the difficulty of mounting this large offset assembly for remachining. However, the individual components for a new housing could be purchased from NEC for a fraction of the cost of an entire new source, modified, and welded up in university shops.

4) Planned development 2004-2005

We will shortly install a new preacceleration assembly for improved pumping, replacing the 4" ID NEC preacceleration tube with a Ceramaseal insulator with 5" ID internal shield. This is possible because we now support the source on the high voltage rack, so the insulator is no longer a structural member. We are also redesigning the extractor section for further increases in conductance and improved reliability. The present 5" ID unshielded NEC external insulator will be replaced by a section of 6" beam pipe with new internal electrodes mounted on ceramic posts.

Spherical ionizers provide inherently better focusing than the standard NEC conical design, and hopefully will allow us to increase source output while maintaining or even reducing the present beam emittance. We have begun testing NEC spherical ionizers with modified ionizer shroud and Cs focus geometries, and we are also constructing a new ionizer assembly to test the Spectramat ionizers used in the LLNL and HVEE sources. The Cs focus electrode in the present source will be replaced with an immersion lens at cathode potential, providing improved local pumping as well as increased clearances between electrodes in the critical central region of the source.

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Figure captions

Figure 1. The NEC 40-sample ion source and sample changer. Note the tight clearances between the outer shroud of the ionizer assembly and the Cs focus electrode, and the lack of shielding of the post-type Cs focus support insulators (one of three is shown). The ionizer assembly is supported by three legs (not shown here) from the same internal lugs as the Cs focus electrode.

Figure 2. The new ion source body with the modified Cs feed, showing the top flange of the Cs oven and the delivery tube extending up into the source to the ionizer assembly. The end of the new ionizer heater feedthrough is just visible at the top left.

Figure 3. The track system built into the source high voltage rack to allow the source to be serviced in-situ. The source is supported from the inner rails of the track system via brackets mounted off the sample changer gate valve housing.

Figure 4. Old and new extraction assemblies, showing the larger pumping apertures of the new design.



