Ion Source Workshop
MC-SNICS Areas of Improvement
At NEC, Middleton, Wisconsin
November 3-4 2003

NSF has funded AMS labs at University of California at Irvine, University of Arizona, and Woods Hole to work with NEC on the MC-SNICS source, to improve reliability and serviceability and to increase output. A small ion source workshop was held at the NEC plant on Nov 3-4 2003 to discuss problem areas and to come up with an initial set of modifications that the three labs could try. Changes already implemented at other labs were also discussed, and there were also presentations on the high-intensity LLNL source and the new PRIME "rabbit" sample changer source.

Attendees

Roger Loger, Greg Norton, Jim Raatz, NEC, 608-831-7600, NEC@pelletron.com
Warren Beck, U of Arizona, 520-621-4277, wbeck@physics.arizona.edu
Dana Biddulph, U of Arizona, 520-621-6285, biddulph@physics.arizona.edu
Tom Brown, CAMS/LLNL, 925-423-8507, tabrown@llnl.gov
Marc Caffee, PRIME lab, 765-494-2586, mcaffee@physics.purdue.edu
Paul Hausladen, ORNL, 865-574-4691, hausladenpa@ornl.gov
David Knies, NRL, 202-767-5659, knies@ccs.nrl.navy.mil
Karl von Reden, WHOI/NOSAMS, 508-289-3384, kvonreden@whoi.edu
Mark Roberts, WHOI/NOSAMS, 508-289-3654, mroberts@whoi.edu
Guaciara dos Santos, UC Irvine, 949-824-3674, gdossant@uci.edu
John Southon, UC Irvine, 949-824-3674, jsouthon@uci.edu

The following points emerged at the workshop and in discussions afterwards:

Higher outputs.

Sample preparation changes (eg graphite production for ^{14}C labs) are lab specific and outside of source design considerations.

Better vacuum, higher cathode voltages, and the ability to deliver more Cs on to the sample itself rather than all over the source, are all important for producing more current.

For a given geometry and cathode voltage there is a space charge limited current from the ionizer that cannot be exceeded regardless of how much Cs is pumped into the source. The AMS group at ANU ran systematic tests to determine these limits and thus avoid overcesiating the source in an effort to get more current. Higher cathode voltages help because the space charge limited current goes as $V^{3/2}$, but only if arcing in the source can be avoided and if the accelerator system can handle any emittance increases. Most of the sparking in the source is presently between the sample wheel and the Cs focus electrode, so this region may be a limiting factor for high voltage operation.

When the source is operated at high Cs currents, the Cs focus point moves back several mm further from the ionizer. Furthermore, high Cs currents require high Cs focus voltages to increase the electric fieldd at the ionizer surface, and as ANU researchers have pointed out, at these voltages the Cs focus electrode actually defocuses the beam, moving it back even further. To get a good Cs focus on the sample at high currents (and hence good negative ion output) the sample wheeel must be moved back several mm. Georgia and UC Irvine are running about 3mm back from the factory setting, and Glasgow are 5mm back.

Vacuum, better pumping.

NEC already has an existing gas cathode source which incorporates a pump port on an extended sample gate valve housing. Consideration could also be given to adding a port on the sample wheel housing, but there isn't much room except on the big 134-sample source. One possible use for a relatively small port might be to try out a UV light source desorption unit to speed up outgassing. Since the source vacuum (measured at ANU) ultimately reaches the 10^{-7} torr range, the major purpose would be to reach the ultimate pressure quicker and decrease downtime after a maintenance. The suggestion was made to make all parts out of stainless steel (including the wheel housing which is presently aluminum) but this would be very expensive, and for some parts (eg the source wheel) raises cooling issues.

The extractor assembly has been drilled out extensively to improve pumping, but still represents a major pumping restriction. Could more be done to open the assembly up?

The sample wheel bellows and the inside of the wheel housing are hard to clean, and stray Cs and corrosion build up and become sources of water, slowing pumpdown. The bellows can be cleaned in-situ by extending it and squirting it with water followed by lots of alcohol. It can also be removed for a more thorough cleaning without affecting the wheel alignment. Access to the rear bolts is via holes in the external indexing disk on the sample changer.

It is useful to be able to measure vacuum in the source itself, at least for tests. A suitable 1.33" Conflat port already exists where the bleedup valve is mounted on the sample changer gate valve housing. At UC Irvine, a tee and a mini- ion gauge head have been mounted between the port and the bleedup valve. Pressure differences between the sample changer (Ps) and in the downstream pump tee under a Cryotorr 8 (Pt) were very large:

Bringing the source up after a sample wheel change:	Pt	3×10^{-6} torr
	Ps	1×10^{-4} torr
Run starting, ca. 1 hr after wheel change :	Pt	2×10^{-6} torr
	Ps	4×10^{-5} torr
2 hrs after wheel change:	Pt	7×10^{-7} torr
	Ps	2×10^{-5} torr

Remote wheel positioning

Arizona are investigating the use of stepper motors on the cathode wheel indexing (to speed up sample changes). There was discussion of the pros and cons: a major problem is to ensure that any sample changer electronics at high voltage is spark-proof. Passive shaft encoders where only light is transmitted to and from the sensing head are available, as are air turbine motors. Arizona are also studying how to remotely adjust the three brass knobs that adjust the wheel position, using gear trains driven by stepper motors or insulating rods.

The Vienna (VERA) lab have implemented a low-tech system for lateral adjustment of the wheel (no in-out adjustment possible) using steel line with rods mounted off the sample changer support brackets. Line is wound around the two upper knobs so they counter-rotate when one rod is turned. This gives sideways motion. The other rod is linked to the bottom knob to provide up-down adjustment. The "wheel insert" air has been turned off to reduce thrust on the knobs so they turn more easily. Atmospheric pressure pushes the wheel forward when the wheel housing is evacuated.

Cs feed and oven

The standard NEC technique of "burping" the source probably introduces a plug of liquid Cs into the bottom part of the feed tube, where the boil-off rate can be controlled sensitively by varying the line heater current. This works well in the hands of a skilled operator, but for mere mortals it is all too easy to flood the source with excess Cs.

Part (most?) of the problem is a cold spot where the upper VCR fittting in the feed line leaks heat away to the mounting bracket. Several labs have found that running the line heater very hard (45A), and/or wrapping the fitting with additional insulation, help keep this area hot enough to allow the Cs flow to be controlled using the oven heater without "burping". However, the system is still touchy and relatively slow to respond.

UC Irvine have copied the LLNL Cs oven, which is built around 1.33" Conflat flanges, and accepts full Cs ampoules (just break off the top and put the whole ampoule in upright). The oven attaches directly to the upper VCR fitting and brings the oven heater (an inexpensive wrap-around heater from Hotset Corp, Battle Creek, MI) much closer to the cold spot.

A further improvement might involve cutting out the present VCR fitting and replacing it with a modified version where the body consists of an inner Cs line separated by an air gap from an outer sleeve, to reduce the heat leakage from the line. Note that this has not been tested, and it would probably be necessary to cut out and replace the whole inner Cs feed tube to make this change.

A more radical solution is to remove the NEC Cs feed completely and replace it with a vacuum-insulated design as used in the LLNL source. The end of the feed tube is threaded and screws on to a hollow stud on the ionizer shroud, and the line is heated by conduction from the shroud - no line heater is required. A new source body purchased unassembled by UC Irvine has been modified to this design, and works very well. It should be possible to retrofit this design to an existing 40-sample source.

NEC are also working on a new feed that incorporates some of these ideas.

The 134 sample source has additional problems due to the large sample wheel housing. This makes the present Cs line very long (since it has to clear the housing) and the source body is so big that it's not clear whether some of the modifications outlined above are possible. It may be possible to bring a new line in at an angle to shorten the run.

Cs focus electrode design (and removal?)

At Arizona and later at UC Irvine, the skirt of the electrode has been cut away to open this area up for better pumping, leaving the flat portion of the electrode supported on three narrow legs about 3/8" wide. If you do this, retain at least some of the bend where the flat transitions to the skirt (ie, cut below this point) to provide the cut-down electrode with some rigidity.

With spherical ionizer designs (see below) it is not clear whether a Cs focus will be necessary, though without it, the design of the ionizer shroud will require careful optimization using electrostatics codes. The advantage of removing this electrode is that at present, the unshielded Cs focus insulators get dirty and eventually become tracked. Arizona tried "mud flaps" to shield the insulators, but they removed them when it appeared that the spectrometer measurement performance was being affected. Insulators which are only dirty (ie, not tracked) can be cleaned with emery, or with 50% HCl.

Spherical ionizers

ANU produced spherical ionizers of about 1.5 cm spherical radius themselves by disassembling existing ionizer assemblies and deforming the front conical surface. The Cs focus electrode was reshaped to conform to an equipotential, as determined from electrostatics calculations using SIMION. This combination produced a significantly better focus of the Cs beam at the sample.

NEC have supplied ionizers with a 1" spherical radius to U of Georgia and UC Irvine. At Georgia a new spherical ionizer was inserted in place of an old severely-worn conical ionizer. Keeping distances, voltages, and Cs temperatures the same, ^{12}C currents were 20-30% higher with the spherical ionizer than with the conical ionizer. It is possible that the increased currents could have just been the result of a new clean ionizer but this is considered unlikely. Compared to the conical ionizer, cesium spot sizes using the spherical ionizer were larger but still within the 1 mm hole size.

The experience at UC Irvine was very different: there was no increase in output, and sputter marks indicated that the Cs waist was well back beyond the samples (even though the wheel had already been moved back several mm). In view of the successful outcome at Georgia, the experiment was recently repeated with similar results: at a similar temperature and Cs focus setting the waist was several mm back compared with the conical ionizer. This suggests that a smaller spherical radius might be more suitable.

Ionizer lead

The lead from the ionizer to the feedthrough becomes brittle after it has been heated, and is the weakest link in the longevity of the ionizer assembly. NRL has crimped a 12 gauge Cu wire to the broken stub, and this has worked well. UC Irvine have used a sleeve with set screws (available from Ceramaseal) to reattach the broken end. Note that it is possible (though nervewracking) to bend the brittle ionizer wire in the process of making such repairs, by heating it to red heat with a gas torch.

The small screw that secures the ground end of the ionizer wire to the leg of the baseplate can sometimes loosen up due to thermal cycling, and in extreme cases the ionizer will go open. Any time the source is open for major maintenance, it's a good idea to check that this screw is tight.

Ease of maintenance: service platform, ionizer assembly and Cs focus removal, source cooling

UC Irvine has built a track or rail system into the "phonebooth" high voltage rack for the 40-sample source. This provides a service platform to support the source while it is taken apart in-situ, greatly improving ease of maintenance. This modification requires that the rack be bolted to the floor, but this is essential in earthquake country, anyway. The rails use cheap filing cabinet slides – longer versions of the ones that support the sample changer - and the source is supported from the sample changer gate valve where the NEC-supplied shipping fixtures are attached. Sketches are available from UC Irvine. (NB if you do this, do not remove the big insulator which normally supports the source. It is still useful for supporting the source if you ever have to work on the internal mechanism of the gate valve).

With the rail system in place, maintenance becomes even easier if you only have to open the source at one end for specific tasks. Locknutting the bolts which secure the downstream ends of the Cs focus insulators allows the electrode and the insulators themselves to be replaced entirely from the upstream end of the source. Also, once the Cs focus electrode is cut back as described earlier, clearances between the ionizer assembly and the focus electrode increase sufficiently that the ionizer can be removed from the downstream end with the Cs focus left in place.

A further aid to maintenance is to have the downstream end of the source body run cooler, so it can be worked on immediately without having to let it cool down, and also to allow the wire seal joint to be replaced by an O-ring. UC Irvine have had a cooling channel machined into the downstream flange of a new ion source body before it was welded up. This could probably be retrofitted to an existing 40-sample source, but would be much more difficult with the large 134-sample source body.

Extractor assembly: shielding, cleaning

The present design does not allow for shielding the extraction insulator, because the active element of the einzel lens is mounted off the insulator itself. This is not a major problem UNLESS too much Cs gets into the source. Once this happens, however, sparking (probably from the sharp edge at the upstream end of the insulator assembly to the extractor element itself) becomes uncontrollable until the assembly is cleaned. At University of Arizona this assembly typically only requires cleaning once a year or so, but UC Irvine and U of Georgia, running the source harder, have both had trouble with sparking.

There was some discussion concerning making all parts out of stainless steel to ease cleaning. However, sonicating the whole assembly in distilled water seems to clean up the aluminum very well.

The insulators themselves are cleaned by wiping them several times with water on Kimwipes, followed by one or more wipedowns with alcohol. They are then heat-gunned dry. Sometimes a couple of these treatments are required to bring the impedance (as tested with a Megger) back up to several hundred Megohms.

Extractor current runaway: ionizer edge.

There is a tendency for extractor currents to rise uncontrollably over periods of several hours. Sputtering marks suggest that this is ultimately due to electron emission from the ionizer, from a sharp edge in the central ionizer aperture facing the extractor element. Positive ions sputtered from the extractor can then flow back into the source. The sharp edge will be folded over in new ionizers.

A redesigned extractor electrode supplied to UC Irvine by NEC, with the conical snout replaced by a straight large-bore tube, reduced the problem by reducing the electric field at the ionizer. This design requires a much shorter internal collimator assembly, eliminating the first collimator, but so far this has not produced any degradation in measurement performance.

Cooling: sample wheel

There are some difficulties with liquid cooling in the cathode wheel hub since this volume is not completely filled with liquid. Deposits can build up near the "shoreline" and these can short out the high voltage. NEC has a nylon tube which is inserted into this region to prevent the buildup of crud near the shoreline. NRL has run for a significant period with no cooling whatsoever. However, it was pointed out that there is a danger of running with coolant in the hub assembly but no circulation. In high heat, the coolant will decompose producing a sludge which can clog the system.

Sparking problems: sample wheel materials and contact, cleaning Cs focus and wheel.

The source has a tendency to spark after a wheel is changed, sometimes for several hours. This is often the major bottleneck in bringing the source back online quickly after changing wheels.

Some of the problem is due to poor contact between the spring-loaded cathode feedthrough plunger and aluminum sample wheels. UC-Irvine and NRL have decreased the sparking by using different contact materials. UC Irvine skimmed the front of the wheel flat and bolted on a stainless steel faceplate. NRL use a copper ring let into the front surface of the wheeel and secured with screws from the back. Using a longer and heavier gauge spring on the plunger also helps, particularly if the source is being operated with the wheel moved back from the factory setting. However, a steel spring cannot survive the heat and periodically requires re-stretching. It may be possible to replace it with Mo/W alloy.

The sparking also seems to be associated with buildup of a very hard deposit (aluminum carbide?) on the Cs focus electrode, particularly if this deposit starts to flake off and expose sharp edges. The problem may also have to do with buildup of Al oxide/hydroxide on the wheel around each sample position, where stray Cs eventually sputters a pit that is difficult to access for cleaning. Periodic cleaning of the Cs focus definitely helps. U of Arizona uses a 50% HCl solution to remove deposits from the Cs focus immediately upon opening the source. UC Irvine uses a diamond-tipped Dremel tool to grind off the deposit. The recessed pit around each sample in the wheel can be cleaned effectively with a Dremel wire brush (NB. USE EYE PROTECTION - these brushes occasionally shed wire).

Recent experience at UC Irvine suggests that regular cleaning of the small sputtered pit around each sample position on the wheel is the most effective way of combating this problem. Wheels are now wire brushed once or twice a week, and there may even be advantages to doing it every time a wheel is prepared for sample loading. If this area around the sample is indeed the major culprit, this may explain why burping the source helps: this would cover any insulating Al corrosion products on the wheel with excess Cs, preventing buildup of stray charge.

Sample wheel design.

The 134 sample wheel is very heavy. It could be lightened by drilling suitable holes, making sure that there is no line of sight to the bellows behind. A system of thin metal shields could prevent this.

The present sample wheel contains a large number of nooks and crannies that are difficult to pump, primarily in the spring-loaded plungers that hold the samples in position. A new NEC 40-sample wheel design is available that uses a single leaf spring to secure all 40 samples, avoiding most of this complexity.

NEC's sample holders are too small to label. UC Irvine has designed a new wheel made from stainless steel and copper, that uses 1/4" by 1/2" cylindrical cathodes that are large enough to write on. The present sample holder design loads from the front but a back-loading NEC type system would also be possible. Beam currents are equivalent to those with the standard sample holder design. The diameter is large enough that all of the beam halo falls on the sample holder and does not sputter the wheel itself.

Bleed resistors.

The Cs focus bleed resistors are very low impedance, so that bleed currents are unnecessarily large. NEC has already changed the design to remove these very large, hot resistors, thus contributing to reduced global warming.

Emittance measurements

If the source output is increased, emittance will probably increase, and it's important to know what the actual source emittance is, to have a feel for when beam will start to clip in the stripper or elsewhere. NOSAMS plans to add a second BPM to the injection line for emittance measurements. (Two BPM.s, or a BPM and a set of adjustable slits, can define a waist diameter and a divergence and hence an emittance).

Electrostatics codes

SIMION is readily available, though not particularly easy to use. Its treatment of space charge is approximate but it seems to give similar results to codes which use more sophisticated algorithms. NEDLAB does a better job of space charge but works only on Mac G3's at present, and is slow. A new G4 version is under development. Space charge does make noticeable differences to equipotentials and beam trajectories in high-intensity sources and an approximate treatment is a lot better than none.