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HIGH INTENSITY NEGATIVE PROTON BEAMS FROM A SNICS ION SOURCE

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For the past year we have been involved in a project to develop an intense (>100μA) negative proton beam from a SNICS (Source of Negative Ions by Cesium Sputtering) ion source. This report will cover how we accomplished and exceeded this goal by more than 40%. Included in these observations will be the following: A description of an effective method for making titanium hydride cathodes. How to overcome the limitations of the titanium hydride cathode. The modification of the SNICS source to improve output; including the installation of the conical ionizer and the gas cathode. A discussion of problems including: poisoning the proton beam with oxygen, alternative gas cathode materials, the clogging of the gas inlet, long burn-in times, and limited cathode life times. Finally, how to optimize source performance when using a gas cathode, and what is the mechanism by which a gas cathode operates; facts, fantasies, or myth.

High Intensity Negative Proton Beams from a SNICS Ion Source

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Abstract

For the past year we have been involved in a project to develop an intense (>100 μA) negative proton beam from a SNICS (Source of Negative Ions by Cesium Sputtering) ion source. This report will cover how we accomplished and exceeded this goal by more than 40%. Included is a description of how to make titanium hydride cathodes, and how to overcome the limitations of the titanium hydride cathode by using a gas cathode. The SNICS source modifications were to install the conical ionizer and the gas cathode. Some problems were the poisoning of the proton beam with oxygen, the clogging of the gas cathode's gas inlet, long burn-in times, and limited cathode life times. Finally, optimizing source performance when using a gas cathode is discussed.

Introduction

The goal was 100 μA of negative proton beams out of a modified SNICS I source (which is very similar to the SNICS II source shown in figure 1) made by National Electrostatics Corp (NEC). This proton beam should come on instantly and last forever (or at least 15-20 hours). The development included a procedure for making high output titanium hydride cathodes, and later included designing a high output gas cathode. The modifications to the SNICS source included; installing the gas cathode and installing the conical ionizer. Some problems experienced were: long start up times, short cathode life times, vacuum leaks while running gas cathodes, and the filling of the gas cathodes gas inlets with sputtered materials. Finally, sliding the cathode out of the source effects the focus of the cesium on the cathode; the cathode position effects total proton output.

Cathode Preparation

A good cathode requires fresh titanium hydride material. It is suspected that titanium hydride loses hydrogen with time. Caution: when creating a hydride remember that hydrogen is flammable, and that mixing of hydrogen with air or oxygen may create an explosive mixture. Do not blow up your lab! See figure 2 for a drawing of the furnace set up. The basic set up consists of a bottle of hydrogen gas that has its regulator adjusted to 2 psi. The hydrogen gas flows through a quartz tube furnace and out an exhaust hood. The flow of the hydrogen gas is limited by a needle valve at the tube furnace inlet; and the flow is observed by bubbling the gas through a 1 liter lab beaker half-filled with roughing pump oil. One bubble every two seconds is adequate. The exhaust of the oil filled beaker is vented to an exhaust hood that is well away from any source of ignition. The tube furnace should be capable of at least 600° C and be

equipped with a controller that will allow for a slow ramp up of the temperature.

Procedure for making titanium hydride metal

1). While the tube furnace is off and at room temperature load the furnace with the titanium metal. The titanium should be in the center of the furnace adjacent to where the thermocouple is located. This thermocouple is outside the quartz tube and is used to regulate the temperature of the furnace.
2). The tube furnace should then be purged with an inert gas such as argon. This will purge the air removing the oxygen from the tube furnace. This can be accomplished by hooking up a bottle of argon to the flow rate control valve and flushing the entire system of any air.
3). Before heating the tube furnace, hydrogen flow is initiated at a rate of one bubble every two seconds. This hydrogen purge continues for two hours.
4). Using a programmable temperature controller ramp the temperature from room temperature to 600°C over a three hour period of time. Should the heating process cause any oxygen to out gas from the materials being heated, this slow rate will allow the gasses to be purged.
5). Once the furnace is at 600°C keep it there for three hours. The flow of hydrogen is kept constant during this time.
6). Turn off the furnace and let the material slowly cool back to room temperature over the next 16 hours. It is important that hydrogen gas flow is maintained during the entire cooling time, otherwise oil may be pulled into the furnace causing contamination.
7). Turn off the hydrogen and again purge the entire apparatus of hydrogen with an inert gas such as argon. This will safely remove all hydrogen from the furnace area.
8). It is now safe to remove the titanium hydride material or your in-situ titanium hydride cathodes. You should observe a change in color of the titanium to a metallic blue or green color.

Two more observations: First the titanium metal will expand. When the material remains intact this dimension increase appears to be approximately 5% (0.125 inch rod increased to 0.131 inch). Second, the titanium hydride metal is brittle and may fracture easily.

The first high output cathodes were made from fitting broken chunks of titanium hydride material into specially carved cavities on our copper cathode blanks. This posed problems since the metal was brittle and would chip and fall out of the cathode.

Procedure for making in-situ cathodes

Fitting the titanium hydride to the copper after the hydride anneal is time consuming and costly. Instead, place the titanium metal into the cathode blank before the hydride processing. The titanium expands to

fill the cavity in the cathode blank during the hydride anneal. This one step process is nick-named the "in-situ cathode". The in-situ cathode is made with titanium rod (either 1/8 inch diameter or 3/16 inch diameter) cut to 1/8 inch length and placing it into a 5% oversize hole (0.131 inch) in either a copper or aluminum cathode blank (use oxygen free hard copper or 6061-T6 aluminum). This is then placed in the hydride furnace and the titanium expands to fill the hole in the cathode blank. Both copper and aluminum cathode blanks survive the hydride furnace fine. Performance can be better from the 3/16 inch rod but this depends on the focus of cesium on the cathode and the type of ionizer being used.

Performance of fresh titanium hydride cathodes

Figure 3 shows beam current output as a function of time from one of the first high output cathodes. The data was taken February 11, 1991. The cathode was made of a small chunk (less than 1/8 inch irregular shape) of titanium hydride tightly wedged into a copper cathode blank. The SNICS source was configured in its original configuration: it had the original cathode holder, it was running a cylindrical (old style) ionizer (which could not focus the cesium sharper then a 3/16 inch corkscrew type bore). The ionizer current was 24.8 A for the first two hours and was then increased to 25.2 A. The cesium oven heater was set a 38.5% for a temperature of 172°C. The importance of the output curve shown in figure 3 is three fold: first it shows that a negative proton beam in excess of 100 μA is possible from the original SNICS source, second it shows the problem of a long 2 hour burn in time, and third, a short life time when currents exceed 100 μA.

To make more proton beam, one hypothesis was to start with a larger area titanium hydride material. Looking at the cathode from Feb 11, 1991 the cylindrical ionizer was sputtering an area larger than the titanium hydride material. The next cathode which ran on March 22, 1991 had a larger surface cross section of titanium hydride (3/16 inch irregular shaped). Figure 4 shows the beam current output as a function of time for the March 22, 1991, cathode. The source was run harder, and the source reached a new record. After running the cathode for a little over 3 hours a record of 260 μA negative proton beam was output from the source. Then the source's extractor supply overheated (it had been full on) and it took seven minutes to cool enough to come back on. After re-tuning beam, the source stabilized at >100 μA of beam for the next 3.5 hours. At 4:30 pm the cathode simply quit. Proton output went to zero. The cathode still contained the slug of titanium metal but perhaps it was now hydrogen deficient.

Pursuing a cathode that would be easier to assemble, and start up faster, we went to the in-situ cathode made with a 1/8 inch titanium rod. Then pre-drilled a 0.013 inch hole in the center. It has been reported at the Ion Source Workshop during the Applications of Accelerator in Research and Industry Conference 1988, that a pre-drilled hole, when used with conical or spherical ionizers, delivered more current much sooner. Figure 5 shows such a cathodes performance. It was first run on March 28, 1991, for 1.5 hours, and restarted

on April 1,1991. Total burn in time was still well in excess of two hours. The pre-drilling of the in-situ titanium cathode certainly wasn't 'instant on beam' when using the old cylindrical ionizer. This cathode did not preform as well as the previous cathodes but still had currents in the 90-100 μA range.

The gas cathode

The staff at NEC suggested that a gas cathode and the conical ionizer could offer further improvements. The gas cathode would not be quickly depleted of hydrogen. The conical ionizer would sputter the center of the cathode where the titanium hydride is located. We ordered both. The gas cathode was installed first and was run May 7, 1991, with an old style cylindrical ionizer. An in-situ cathode (made from 3/16 inch titanium rod by 1/8 inch long plug and than annealed) that had a 0.014" hole drilled 0.026 inch off center was used (titanium hydride isn't essential it was just readily available, plain titanium works too). This cathode was run twice, 2 hours on May 7, 1991, and again for 5.5 hours on May 8, 1991 (see figure 6). On both occasions the beam current exceeded 100 μA and appeared to follow gas pressure. Maximum beam would occur when the source pressure was 2.3 X 10^{-6} torr as measured over the cryo-pump near the source. Please note, this cathode was not badly worn, in fact it was modified and used again in October.

After installing the conical ionizer many problems were found. Among them were problems of oxygen poisoning the cathode (i.e. >50 μA tuned oxygen beam). There were vacuum leaks at the gas cathode. The source was not producing as it had previously. Proton beam out of the gas cathode was down to 20 μA maximum.

Modifications to the gas cathode

The gas cathode was modified, adding a pinion gear with a linear vernier slide assembly. This allowed us to move the cathode into or out of the source while the source was running. The cathode would preform very well when it was slid 6 or 7 mm out from its original location. Occasionally, the proton output would jump to 150-160 μA for ten minutes then return to 10 or 20 μA. Inspecting the cathode would show a clogged gas inlet hole. The inlet hole was typically 0.014 inches diameter drilled on the cathode axis center. The hole would invariably clog with sputtered material, titanium or titanium hydride (having tried both).

The solution was to drill multiple gas inlet holes into the titanium or titanium hydride cathode material. Four holes would not all clog. Using the in-situ cathode from May 8th, three more 0.014 inch holes were drilled 0.026 inches from center. In the center was still a broken bit. Figure 7 shows just how well this design really worked. The source still had a warm up time. Source current of 160-162 μA negative proton beam was sustained for several hours. The beam was very well behaved. Reducing the ionizer current would reduce beam output. Likewise, reducing the gas flow of hydrogen into the source would reduce proton production from 160 μA to 23 μA. The in-situ titanium hydride cathode material was contributing to this beam but clearly wasn't the

source of all the beam. The cathode shown in figure 7 continued to run on October 14 and 15th for more than a total of 14 hours at currents exceeding 100 μA.

The cathode was heavily worn but still appeared to have some life left. A visual examination of the cathode indicates that the cesium wasn't coming to a focus in the cathode, but rather was focused very near the surface of the cathode and had crossed over inside the cathode. The resulting sputtered material left a conical cone expanding inside the cathode for a distance of 1/8 inch from the cathode surface. Figure 8 was provided by NEC and shows a computer simulation of a recessed cathode's sputtered wear pattern.

Conclusions

The best performance has been from gas cathodes that have multiple holes drilled for the gas inlets. Two materials have been used for the cathode bodies: both aluminum and copper appear to work equally well. The titanium plug and the titanium hydride plug that inserts into the cathode, when drilled and used as gas cathodes work comparably. The source takes 1 1/2 to 2 1/2 hours to warm up, and the gas cathodes appear to come on 45 minutes faster than the in-situ titanium hydride cathodes. A gas cathode can be expected to run reliably 14 to 16 hours (Late breaking news! An aluminum body cathode with a titanium hydride insert has been run 20 hours at currents of 90 to 110 μA). All cathodes work best when their physical position can be adjusted. An optimum adjustment on our modified SNICS I source appears to be retracting the cathode 6 to 7 mm out from NEC's original design. The emittance measurement of the beam will be done later; and the experiment which uses this beam does have a large acceptance. Finally, when very little proton beam is available out of the source, look for other beams, as vast quantities of oxygen beam reduces the available proton beam.

Acknowledgments

We wish to thank Joe Tesmer and Carl Maggiore for their invaluable wisdom and continued patience, and for their allowing us to try and try (often over their better judgement). Our appreciation to Richard Morgado for his constant enthusiastic encouragement. A big THANK-YOU to Paul Canfield for his help in developing the titanium hydride process. Also, thanks to all the Staff at NEC for always returning our calls, answering our questions, and for being incredibly helpful. Finally, Roy Middleton for writing A Negative-Ion Cookbook a great reference book for doing source development work. This research was conducted under the auspices of the U.S. Department of Energy.

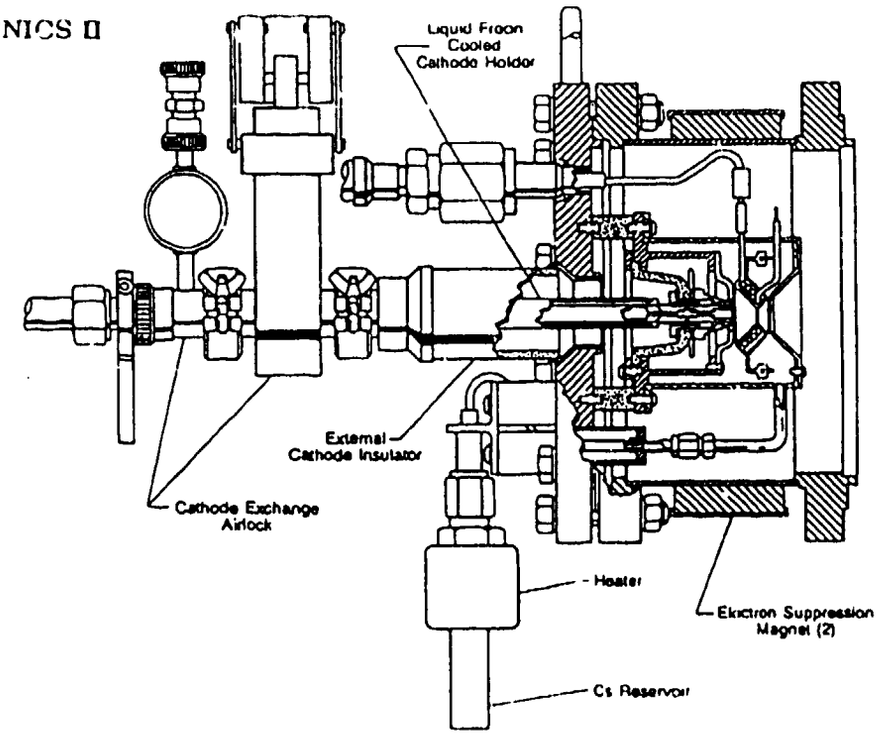

Figure #1 SNICS II Ion Source (courtesy of NEC)

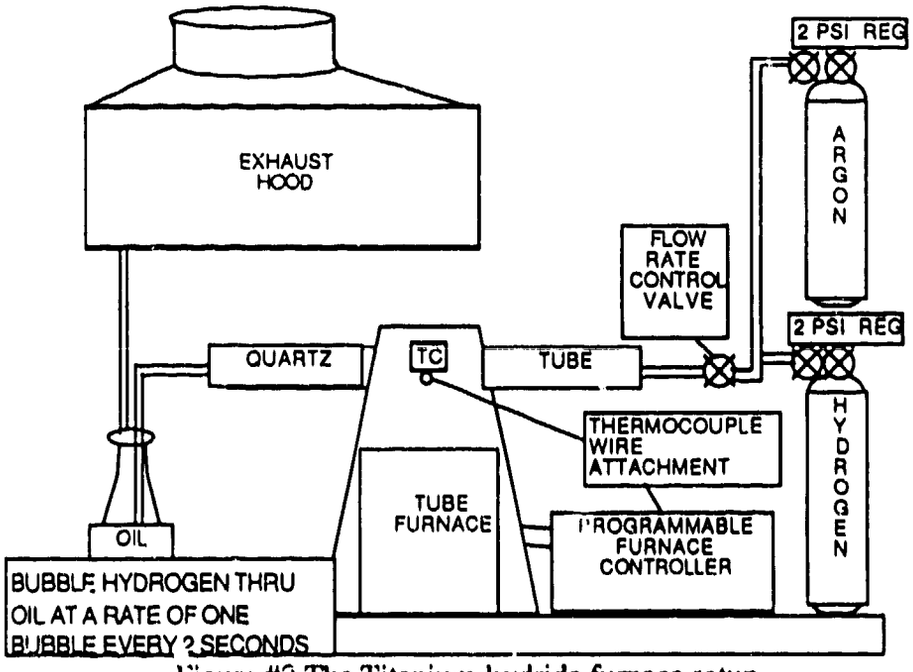

Figure #2 The Titanium-hydride furnace setup

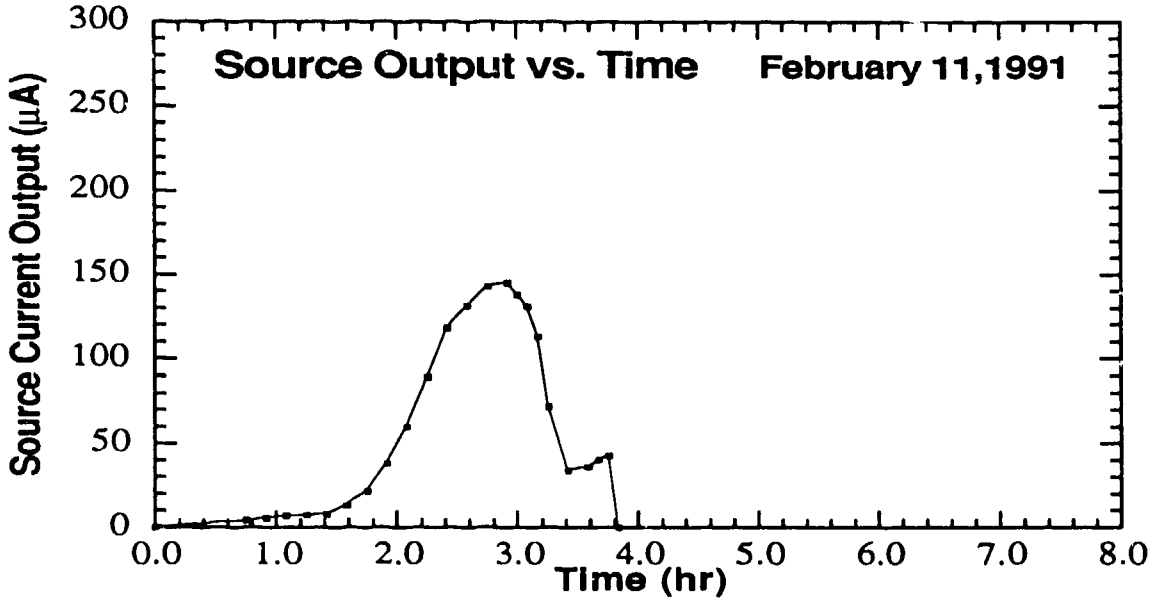

Figure #3 A small piece of titanium hydride in the cathode (< 1/8 inch diameter)

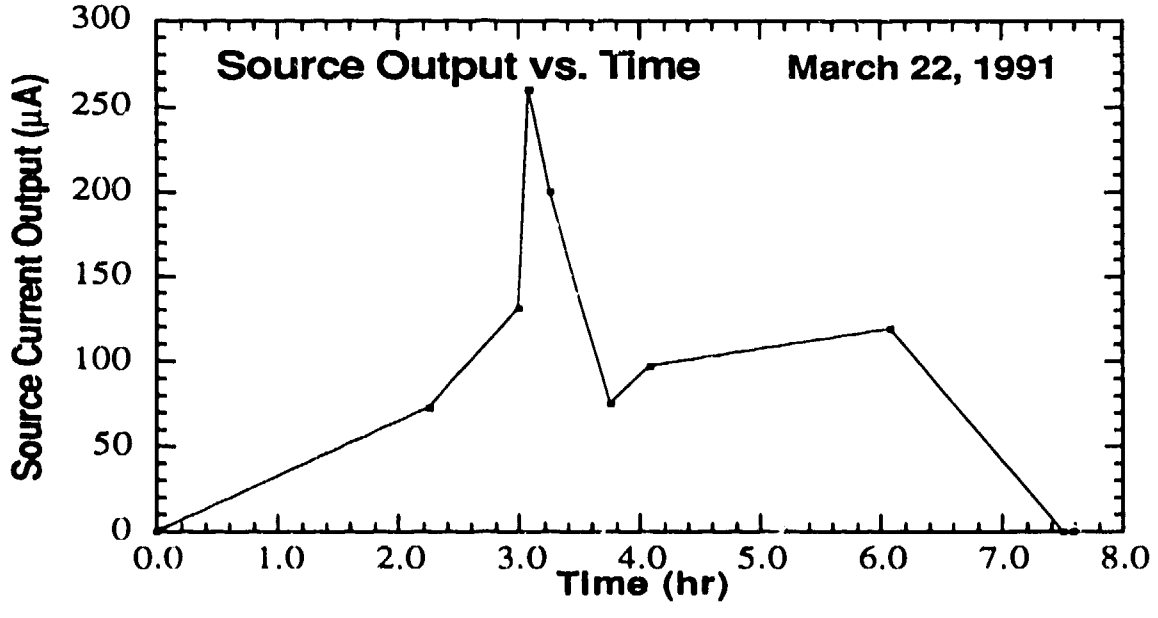

Figure #4 Larger piece of titanium hydride in cathode (>3/16 inch diameter)

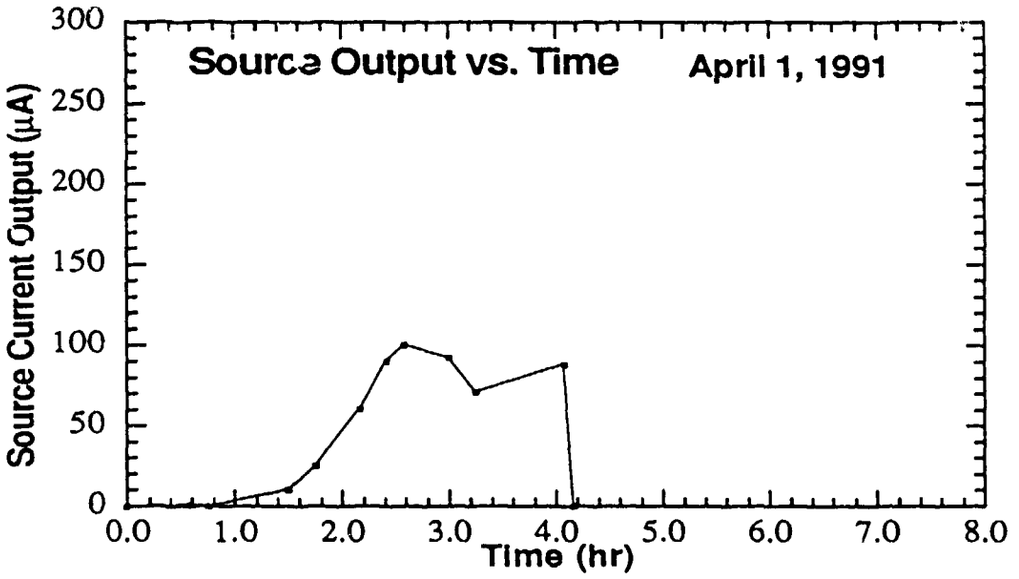

Figure #5 The 1/8 inch titanium hydride rod, in-situ cathode, with a predrilled 0.013 inch hole was run April 1, 1991. The hole was intended to reduce source start up time. It still took more than 2 hours to get 100μA.

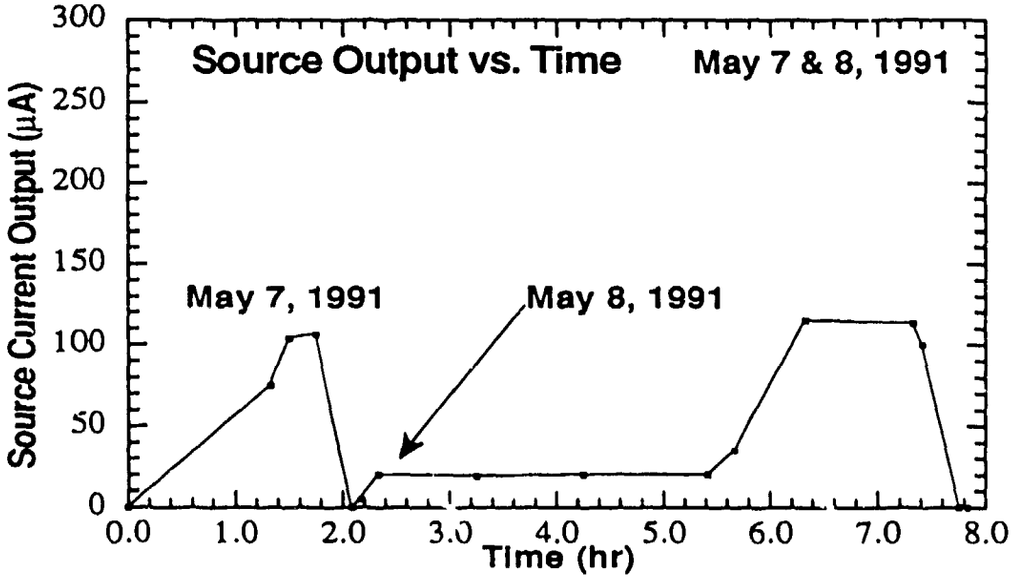

Figure #6 The gas cathode was installed with a single offset (.026 inch offset, a drill bit broke at the center) gas inlet. This data was taken with the old cylindrical ionizer.

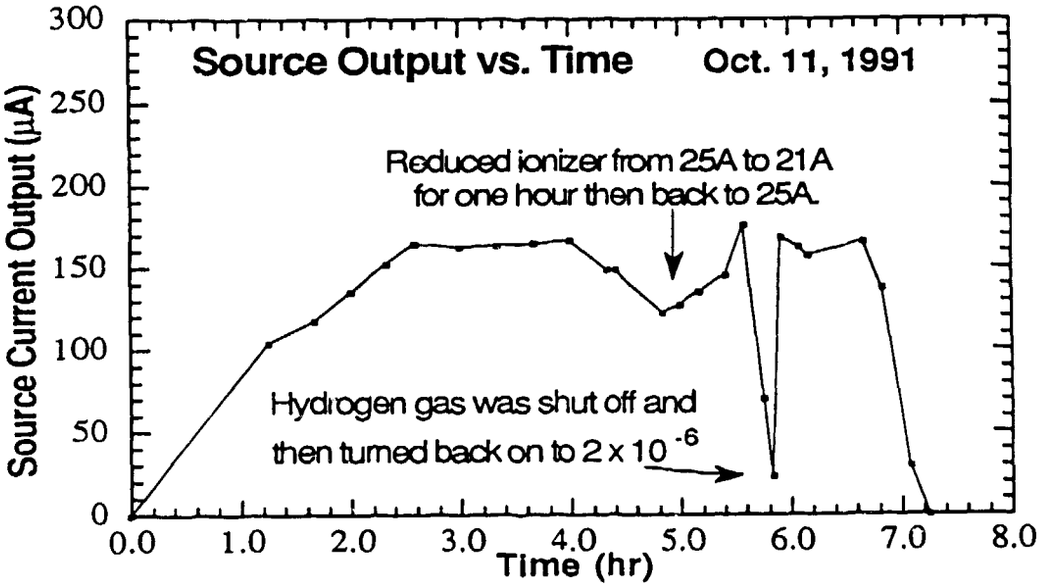

Figure #7 Gas cathode with four gas inlets, retracted 7mm out of source, and new conical ionizer. This is the same cathode used May 7 & 8,1991 but with 3 new holes.

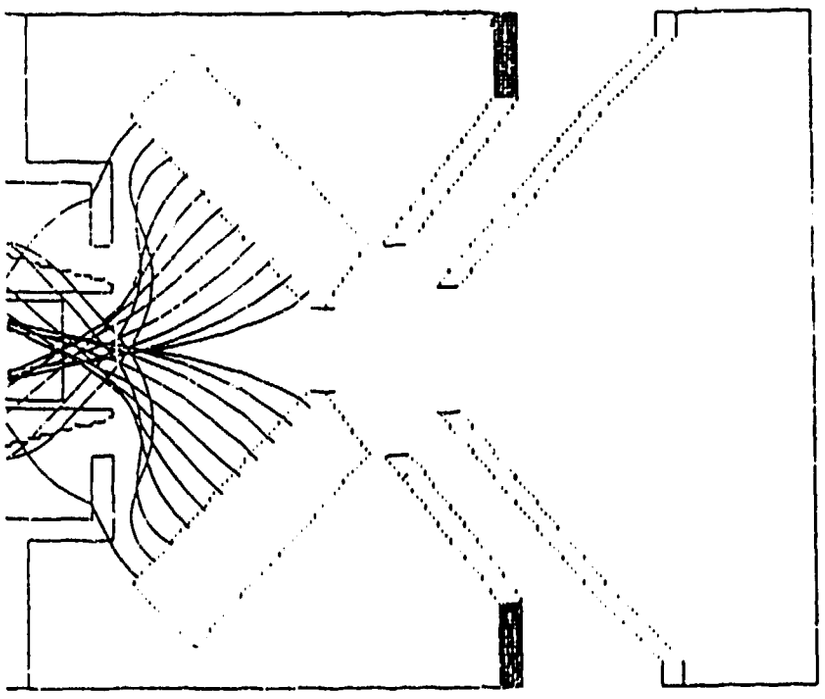

Figure #8 Computer simulation of cesium sputter pattern when cathode is retracted out of source 0.15 inches (courtesy of NEC).