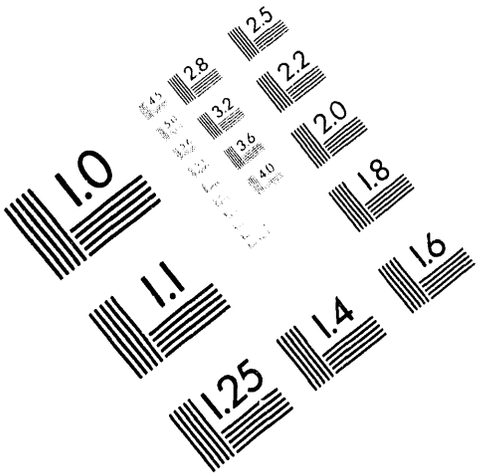

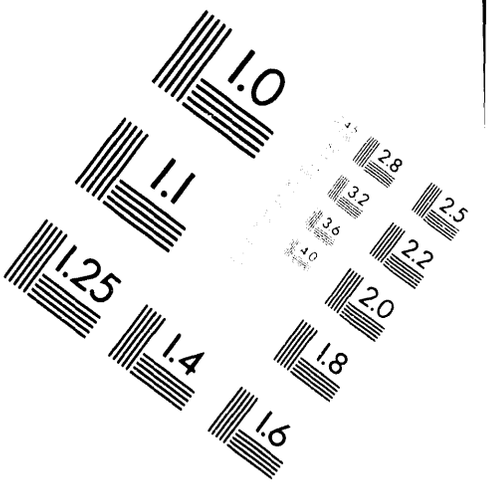

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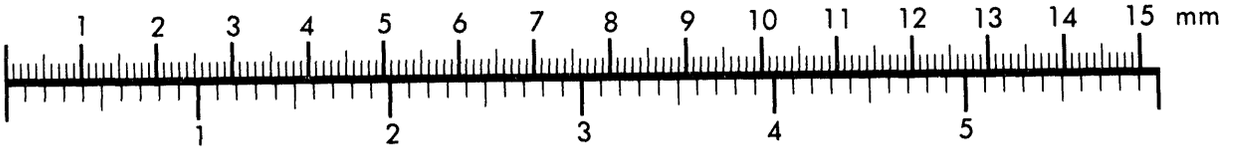

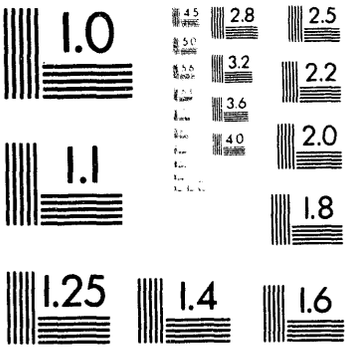

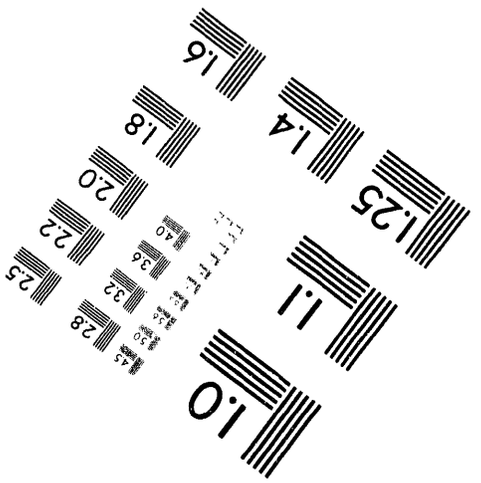

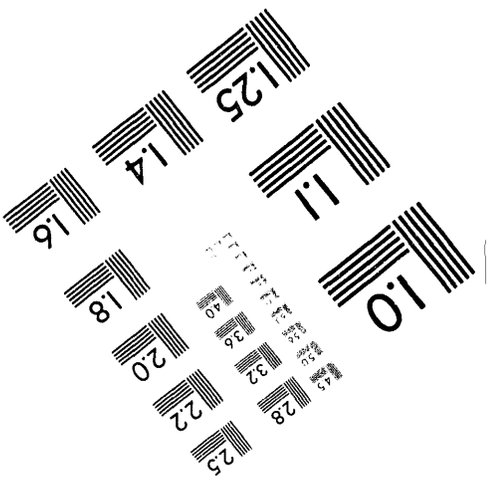

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REMOTE SENSING OF LIQUID WATER TARGET OPERATIONS

R.A. Ferrieri*, D.L. Alexoff and D.J. Schlyer
Brookhaven National Laboratory, Department of Chemistry,
Upton, New York, 11973-5000 USA.

INTRODUCTION

One of the key considerations in the design of automated liquid water target systems for reliable $^{18}F^-$ production is the inclusion of adequate sensing devices for remote feedback of individual process operation status. This information allows for smooth transition between process operations that ultimately avoids production inconveniences such as target damage due to empty target irradiation, or loss of ^{18}F activity due to incomplete recovery of the target contents after irradiation. Such inconveniences can not only result in loss of PET runs, or at least delays in schedule, but result in an increase in the radiation exposure of production personnel as well.

The process operations needed to generate, extract and deliver $^{18}F^-$ to the Hot Lab for subsequent chemistry are not really complex. These involve configuring target valves for access during loading of enriched water, filling the target with water, reconfiguring target valves so that it is sealed during irradiation, and finally emptying the target contents after irradiation.

At the lowest level of remote sensing of these operations is the act of determining whether target valves are actually in their correct configuration for a specific step. Electric feedback of whether a solenoid valve is energized or not is entirely inappropriate in these instances because such valves may fail, and remain either opened, or closed, while yielding false feedback to the monitor. Physical displacement valves such as HPLC injector valves are better suited to this task because feedback of the valves configuration can be accomplished through closure of electric contacts on the valves stem.

Sensing the filling or emptying status of the target is perhaps the most crucial feedback for reliable target performance. One must ensure that the entire charge of water has been loaded into the target confines. Irradiation of partially filled targets can be just as devastating as irradiation of empty targets. Likewise, one must ensure that the entire contents of the target has been emptied after irradiation. This is important not only to maximize production levels of radioisotope, but also to minimize losses of enriched water during subsequent processing.

Sensing the presence, or absence, of liquid water can be accomplished by measuring some physical property of the substance in that phase. For example, we demonstrated (Ferrieri R.A. et al., 1992) that 5 ppm levels of metal cations in water will yield a specific resistance of 0.15 MΩ . This level is more than adequate to detect a response using commercial conductivity meters.

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MASTER

Conductivity probes can be easily installed into the high pressure componentry of the target plumbing using standard HPLC fittings.

Likewise, refractive index is another property of water that can be harnessed for sensing the liquid's presence (Alexoff D.L. and Hallaba K., 1993). For example, the amount of light transmitted from a source through a transparent cell or tube will vary depending on whether the cell or tube is filled with liquid. This later approach possesses the advantage of being non-invasive in detection. Unfortunately, it is not entirely amenable to operations requiring high pressure components, and therefore, is limited in use to operations involving manipulation of liquids downstream from the high pressure target.

$H_2{}^{18}O$ WATER TARGET SYSTEM DESCRIPTION

The Figure shows a complete schematic of the high pressure liquid water target system that is now in operation on the BNL JSW beamline for routine production of $^{18}F^-$. The target is constructed of silver, and is of a standard keyhole design possessing an active volume of 2.5 mL, and two ports for manipulating the water charge. All operations for configuring target valves, loading the target, and unloading the target are controlled by a PC computer either through an RS-232 interface that couples to a short-haul modem, or through I/O triacs for powering AC solenoids. The computer is located in the cyclotron control room.

Target loading is carried out using an infusion syringe pump (Harvard Apparatus, Inc., Model 22). The pump is connected to the target through two 6-port high-pressure HPLC valves (Rheodyne Model 7010) that are remotely operated using pneumatic actuators. These valves configure the target for receiving water from the pump, for high-pressure irradiation, and for unloading the water charge to the vault located resin/recovery station. In the event of line rupture in the N_2 supply driving the pneumatic actuators, the switching valves remain in their last command state thus avoiding a catastrophic occurrence. Electrical feedback is made to a light box via contact switches located on the valve stems indicating valve status at all times during target operation.

All connections involved in target loading are made using standard HPLC fittings, as well as 1/16" o.d. 316 stainless steel tubing to maintain high-pressure integrity. The total load volume of liquid necessary to fill the active target volume and peripheral plumbing is 3.3 mL.

Electrical isolation of the target is accomplished using high-pressure low dead volume nylon HPLC couplings (Waters) on both lines attached to the target. When paired in series, the short length of stainless tube coupling each insulator serves as an isolated probe for measuring the resistance across the nylon gap of each target line. The target filling status can be monitored by carrying out resistance measurements across the isolation gap of the top port line using a commercial conductivity meter (Crystalab Inc., Hartford CT, 120 V AC, 60 cycle, 1/25 W). The target must fill to capacity before water can exit

through the top port and change the resistance across the gap at that location. Likewise, the target emptying status can be monitored in the same fashion across the isolation gap of the bottom port line.

The response range for the above meter covers 3 MΩ to less than 0.01 MΩ, corresponding to metal ion levels of 0.1-50 ppm, respectively. The ^{18}O-enriched water used (Isotec) for ^{18}F-production generally possesses metal ions in the range of 15-20 ppm, more than adequate for good meter response. However, response does drop upon distilling the water during reprocessing. Adequate response can be reestablished by leaving the distilled water in contact with a silver foil for appoximately 24 h before use.

The "handshake" software that is an integral part of the pump's processing software allows the computer to start or stop the pump, and to monitor the volume of water dispensed from the syringe. If the syringe should empty prior to dispensing a complete charge of water to the target, the pump automatically pauses and flags the computer of its status. Once refilled, the computer flags the pump to resume operation.

After loading of the target is complete, the computer places the Rheodyne valves in their proper configuration for sealing the target. As the blow-up of the valve plumbing shows in the Figure, the inlet and outlet ports are coupled during this action. Once the irradiation is complete, the computer reconfigures the valves for unloading. Nitrogen gas forced through the top port of the target during this operation drives the water charge from the target, and into the resin/recovery station.

The resin/recovery station is also located in the cyclotron vault approximately 1 m from the target station. This facilitates target unloading, maximizes $H_2{}^{18}O$ recovery, as well as prevents long-lived contaminants from reaching the Hot Lab. The station that was previously reported by us (Ferrieri, R.A et al., 1992) has been modified to include a new leak-free resin column assembly that is fabricated from a standard HPLC guard column housing. The inlet and outlet holes to this housing are enlarged slightly to prevent flow restriction. The anion resin (Bio Rad AG1X8 carbonate form; 200 mesh) is packed inside a 1/4" o.d. lucite tube that has a polyethylene liner. Polyethylene frits (Alltech) are placed at both the inlet and outlet to the tube as it is mounted within the guard column housing. Connections to the guard column housing are made with finger-tight nylon HPLC connections (Rainin) on 1/16" o.d. polyethylene tubing.

The outlet tube from the resin column passes through an optical sensor which measures light transmission across the plastic tube. The sensor unit emits 915 nm light through a miniature infrared phototransistor (Radioshack) mounted on one side of the plastic tube, and receives it through an equally small photodetector (Radioshack) mounted diagonally across the tube. The amount of light transmitted changes depending on whether the tube is filled or not with liquid. The current output from the detector is of course proportional to the amount of light received. However, with appropriate circuitry the unit can be configured to transmit either a 0 VDC or 5 VDC signal directly to the computer

for remote feedback of the tube's status. This feedback informs the cyclotron operator of when the enriched water recovery is complete. All target operations are then shutdown, thus transferring control of the resin station via "blackbox" operation to the Hot Lab, where the chemist has complete control of radioisotope delivery.

SYSTEM PERFORMANCE

In the six months since its installation, the described automatic high-pressure water target system has been able to make and deliver up to 725 mCi of $^{18}F^-$ (EOB) from a 40 minute irradiation on 95% ^{18}O-enriched water using 15 μA of 17.4 MeV protons on target. The target should be able to tolerate higher beam currents, and thus produce larger amounts of radioisotope, although this aspect has not tested to date. Automatic operations permit target loading and valve configuring for irradiation within one minute. In addition, target unloading and water recovery takes only one minute. Radioisotope extraction from the resin, as well as its delivery to the hot lab in carbonate solution through 40 m x .5 mm i.d. of polyethylene tubing generally takes 5 minutes.

With constant daily use of the system, we have observed significant deterioration in the response of the optical sensor resulting in 50% reduction in sensitivity. Of course, sensitivity of the unit depends on light emission, as well as light detection, both requiring lens that are probably sensitive to neutron damage.. While the unit is housed inside a 1" thick lead hot cell that shields the resin station, we have not taken steps to shield it against the high neutron field induced in the cyclotron vault during irradiation. We have compensated for the change in sensitivity by readjusting the threshold setting of the unit that allows it to transmit a 5 VDC signal to the computer. Eventually, the unit will be rendered nonfunctional as the radiation damage becomes overwhelming, and will have to be replaced.

Acknowledgements: This research was carried out a Brookhaven National Laboratory under contract DE-ACO2-76CH00016 with the U.S. Department of Energy and supported by its Office of Health and Environmental Research, and also supported by the National Institutes of Health, Grant NS-15380.

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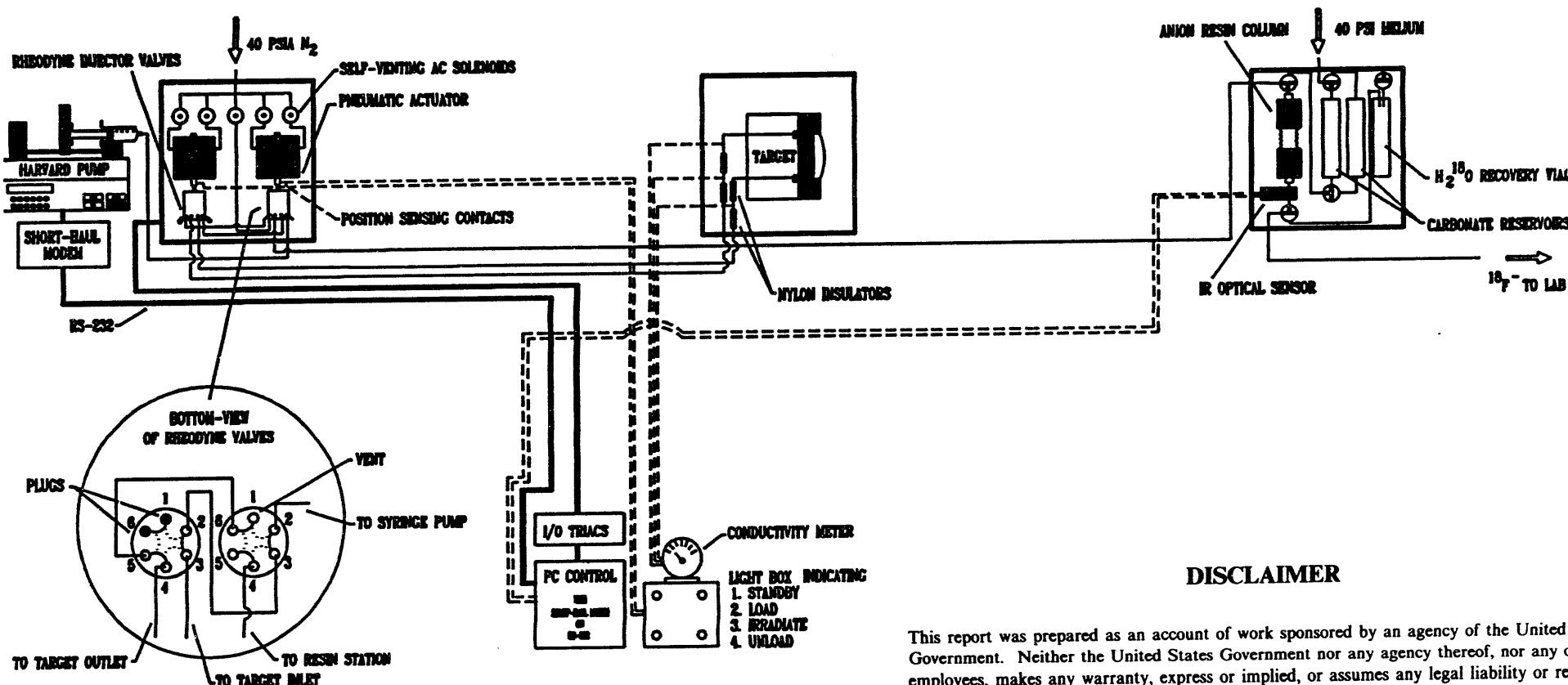

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