TRIUMF	UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER 8, B.C., CANADA			
DESIGN NOTE	NAME J.J. Burgerjon, J. Lenz, B.T. Trevitt	DATE June 13,1979	FILE NO. TRI-DN-79-8	PAGE 1/6

SUBJECT

LONG DISTANCE RABBIT TESTS

Introduction:

The proposed Positron Emission Tomography program (P.E.T.)would utilize the positron emitters ^{18}F, ^{11}C, ^{13}N and ^{15}O with respective half lives of 110, 20, 10 and 2 minutes. These radio-gases may have to be transported to the Intensive Care Unit at the new campus hospital, at about a 2.5 km distance from TRIUMF. A viable system would have a combined transit and processing time no longer than approx. 2 half lives.

Experiments with continuous transfer through thin tubes revealed that this criterion would be very difficult to meet for ^{15}O. (Preliminary Design Note TRI-DN-78-17. Test results still to be written up). Therefore, a batch-transfer system was studied, whereby the gas would be contained in a capsule (rabbit), to be blown through a tube by means of compressed air.

We do not know of a simple method to calculate the transit time for such a capsule. The few manufacturers of commercial pneumatic transfer systems were unable to quote approximate transfer times for their systems, and had never built systems of this length. Therefore, a simple experiment was set up.

Test set-up:

Since extrapolation as a function of length is about as complicated as the direct calculation, a 2.44 km long tube was used for the experiment. The diameter was chosen identical to other rabbit tubes already in use at TRIUMF. 20.7 mm I.D. x 25.4 mm O.D. The material was medium-density poly-ethylene. It is very difficult to obtain accurately dimensioned tubing. Manufacturers are generally not prepared to guarantee a tolerance. Lack of roundness is a particular problem. The tubing is wound in coils after extrusion, which causes it to become oval. We believe our tubing was generally within ± .5 mm on the average inside diameter, and ± .5 mm in roundness.

Ideally the tube should be laid out in a straight length, but this is impractical. As a compromise it was laid out in a coil of about 27.4 m. diameter, which would fit on top of the cyclotron vault. Assuming a transit time of 3 min, and a constant speed for the capsule, this would give a centrifugal force of 1.34 G. This would roughly make up for the effect of corners, which would obviously have a much smaller radius.

The air supply should not be limited by the capacity of the compressor and the impedance of the compressed air line. By connecting into a 1" supply line, which is short compared to the total length of the rabbit tube, the impedance should not be a limiting factor. At the assumed transit time and constant speed, the required air capacity is approximately 500ℓ/min. The site air compressor has a continuous rating of 450 ℓ/min and is backed up by a large storage tank.

Fig.1 shows a schematic of the set-up. To send off a capsule, the tube is disconnected at the valve in the supply line, which is horizontal at that point. The capsule is inserted in the tube, which is then reconnected. The valve is opened suddenly and the travel time is measured with a stop watch.

contd...

To gather information on the speed of the capsule as it moves through the line, capsules can be fitted with a radiation source. A radiation sensor will detect the capsule each time it completes a turn. The signals are registered on a strip chart recorder.

The air pressure was recorded at the start of each run and varied between 5.5 and 6.0 kg/cm^2. During the run the pressure dropped typically .5 - .7 kg/cm^2. The variations in the supply pressure are caused by the on-off cycles of the compressor.

Transit Times:

The only parameter that had a strong effect on the transit time was the diameter. Three sizes were tested: 19.1, 15.9 and 12.7 mm, leaving a nominal clearance between capsule and tube of respectively 1.6, 4.8 and 8.0 mm. The 19.1 mm capsules all had transit times of 178 S ± 4%, the 15.9 mm capsules ran through the tube in 248 s ± 4%, and the 12.7 mm capsules stopped somewhere in the middle of the tube. Taking the diameter and roundness of the tolerances in the tube into account, the 19.1 mm capsule would have a minimum radial clearance of .6 mm. Thus 19.1 mm appeared to be the optimum diameter with respect to transit time. Larger capsules were no faster, or got stuck in the tube. Only some 5 runs were done with 15.9 mm capsules, as they were too slow.

There was a remarkable uniformity in transit time for the approx. 20 runs wit 19.1 mm capsules. All data were within the 178s ± 4% range, which is actually better than the variation in supply pressure. This in spite of the fact that within this series of runs the following parameters were varied.

Material:	Polypenco and Teflon
Length:	51, 76 and 102mm.
Weight:	by 20% (hollow capsule).
End shape:	Flat and rounded edges.

Speed of Capsule:

To gain some insight in the mechanism of propulsion, the velocity of the capsule was measured as described and is plotted in Fig.2. The initial velocity of the capsule is very high indeed, in excess of 100 m/s, It then slows down to about 9 m/s after approx. 60% of its travel and speeds up again to 20 m/s near the end.

The explanation is, of course, that the capsule travels fastest at a max. pressure difference across it. Due to leakage past the capsule the pressure builds up ahead of it. This pressure is reduced again as the length of the tube ahead of the capsule gets shorter, to become equal to atmospheric at the end of the tube.

This behaviour predicts that if the tube were extended, one would reach a length at which the pressure drop across the capsule becomes too low to overcome the frictior and the capsule would stop before it reaches the end of the tube. This point has already been reached for the 12.7 mm capsule. From the series of tests described in this note it is impossible to predict at which length this would happen with 19.1 mm capsule.

contd...

Recovery Time:

After a capsule has passed through the tube the front end is at a pressure of approx. 6 kg/cm. To obtain the same transit time for the next capsule one would have to wait until the whole tube is at atmospheric pressure again. Fig. 3 shows the pressure at the front end of the tube vs. time after the valve is closed after a capsule has passed through. A waiting time of about 8 minutes would be required to achieve the same transit time with the next capsule. However, by opening the front end of the tube this time can be reduced to at least 25%, or probably 1 to 2 minutes.

Attempts to improve the transit time:

Theoretically the transit time could be reduced if one could make a perfect seal between capsule and tubewall, without increasing the friction. An attempt in that direction was made by attaching a rubber washer to the rear end of the capsule. The results were discouraging and this design was pursued no further. The only way to make a less leaky seal would be to obtain tighter tolerances on tube diameter and roundness, so the average clearance can be reduced.

Again theoretically, the transit time could be reduced if the back pressure could be reduced by a vacuum pump. This pump would have to be located at the end station. Such a pump would be quite capable of evacuating the tube before the capsule is released. We measured a pump down time of 45 min. to reach a pressure of .2 kg/cm^2 at the front end of the tube. This time is determined by the flow resistance of the tube, and a larger pump would be of no advantage.

A (positive displacement) vacuum pump can reach a good vacuum, but has a very low thruput. It would therefore have to be backed by a large vacuum tank at the exit end of the tube. Its volume would have to be some 5 times that of the tube volume to be effective, or at least 4000ℓ.

A (centrifugal) vacuum cleaner blower would be able to cope with the thruput but produces very poor vacuum. This method was tried but produced insignificant reduction of transit time. The effect on the velocity is shown in Fig.2.

Subsequently a mechanical vacuum pump was connected directly to the end of the tube and the vacuum in the tube reduced to .2 kg/cm^2 before releasing the capsule. We see in Fig.3 that, initially, the velocity of the capsule was increased by approx. 50%. Eventually the pump could not cope with the gasload ahead of the capsule, and the capsule came to a stop before it reached the end of the tube. A back-up vacuum tank of the proper size would have prevented this, but was not available.

Reliability:

The burst pressure of low-density poly-ethylene tubing as used for the AECL rabbit system was experimentally determined as 19 kg/cm^2. The burst pressure of the medium-density poly-ethylene tubing used in this test was similarly determined as 43 kg/cm^2. This leaves a wide safety margin considering the operating pressure of 6 kg/cm^2.

contd...

Nevertheless there were approx.6 tube failures (blow-outs). These can not reasonably be explained by wear from the moving capsule. The AECL rabbits system, which now have transported approx. 1500 capsules, never gave any trouble of this kind. An accelerated wear test was conducted by making a 6 m DIA loop in the tubing, increasing the centrifugal force by a factor of 4.5. No visible signs of wear could be detected. After the 6 initial blow-outs, no further blow-outs occurred. The flaws in the tubing where the blow-out occurred must have been caused during the extrusion process, as the thin spots were both on the inside as well as on the outside of the tubing. The manufacturer was not prepared to admit this. The experiment with the 6 m DIA. loop also showed that 102 mm long capsules get stuck occasionally.

Conclusions:

1. The tests prove that it is possible to transport a capsule over a distance of 2.44 km in 3 minutes.

2. The effect of low and average friction material (teflon and polypenco), length (51 to 102 mm), weight (± 10%) and edge shape appears to be negligible.

3. The velocity of capsule is not uniform as was assumed to estimate the centrifugal force. Since this force increases with the square of the velocity, it was underestimated substantially, and actual transit times in a straight lir would be shorter. However, the number and nature of bends in the line are not known at present. Therefore, a transfer time of 3 minutes is considered a safe design figure for a 2.5 km long tube with a 6 kg/cm^2 drive air pressure.

4. If bends of 3 m radius are to be used, the length of the capsules should be limited to approx 90 mm long.

5. One should expect a recovery time of 2 minutes before the next capsule can be sent off. This means one can despatch one capsule every 5 minutes.

6. To reduce the transit time by using an evacuated line is expensive, complicated, and would substantially increase the recovery time. A more promising approach would be to increase the air pressure, at the cost of some of the safety margins in the tube burst strength. A guess is that a factor of two could be achieved. This could not be tested for lack of a suitable compressor.

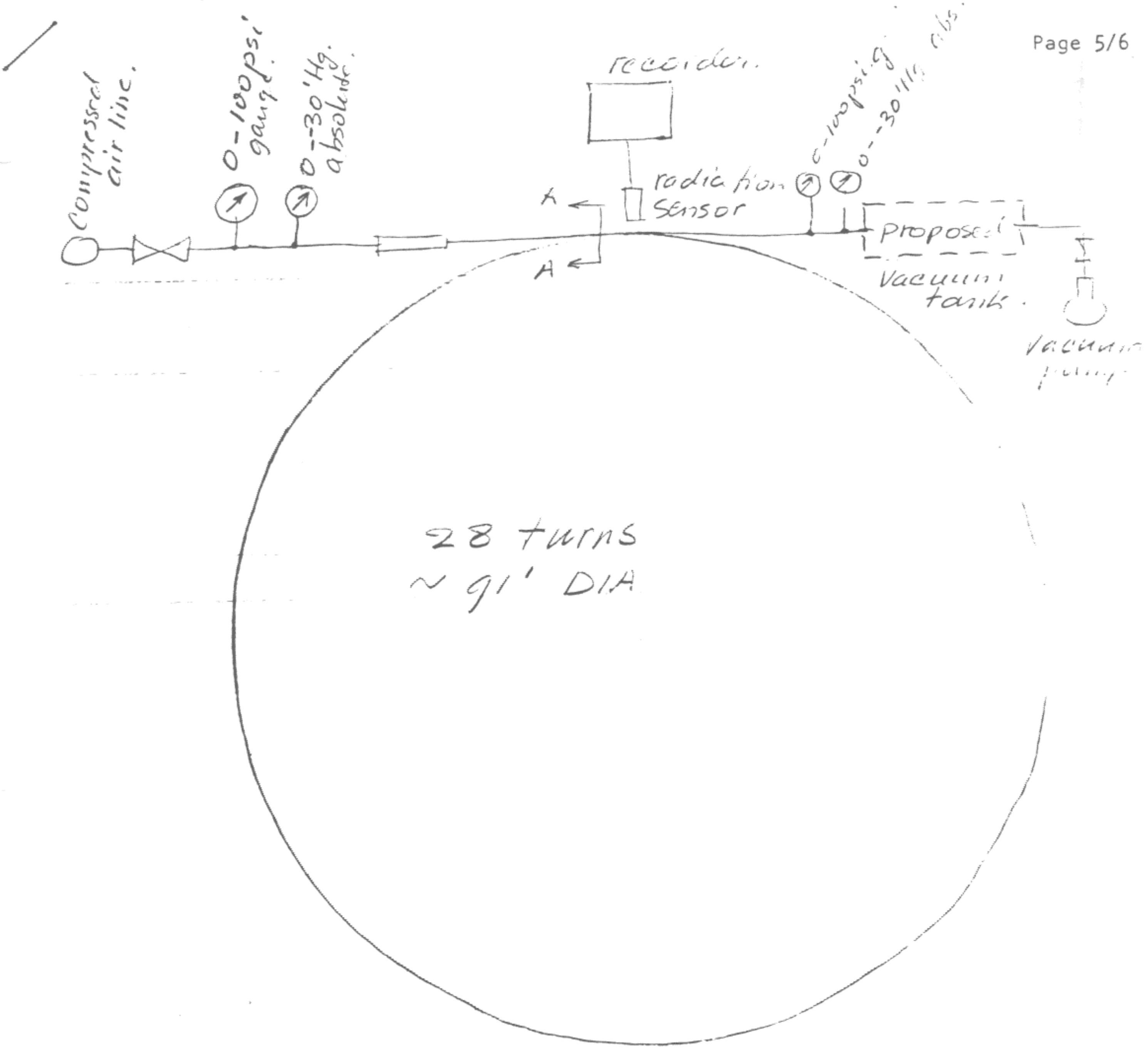
Recommendations:

1. Medium (or high) density polyethelene should be specified as the tube material, on account of strength, cost, and ease of installation.

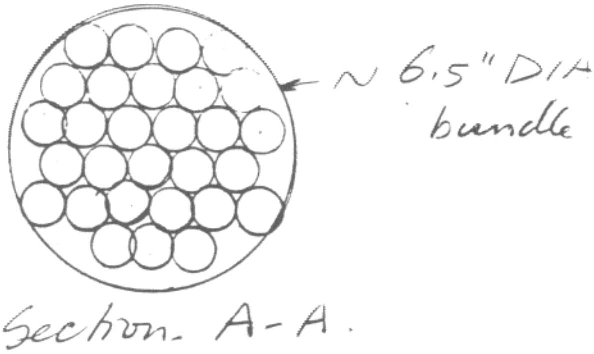
2. The tube bore should be specified as tight as possible, in terms of diameter and roundness. The finished product should be checked by blowing a properly dimensioned gauge steel ball through the tube.

3. The whole tube should be hydraulically tested upto 3 x the working pressure.

4. In view of cost, complexity, marginal transit time and the possibility of environmental concerns (whether founded or not) the P.E.T. laboratory should be located at,or adjacent to,the TRIUMF site.



LONG RANGE RABBIT
TEST SET-UP



Section A-A.

FIG 1

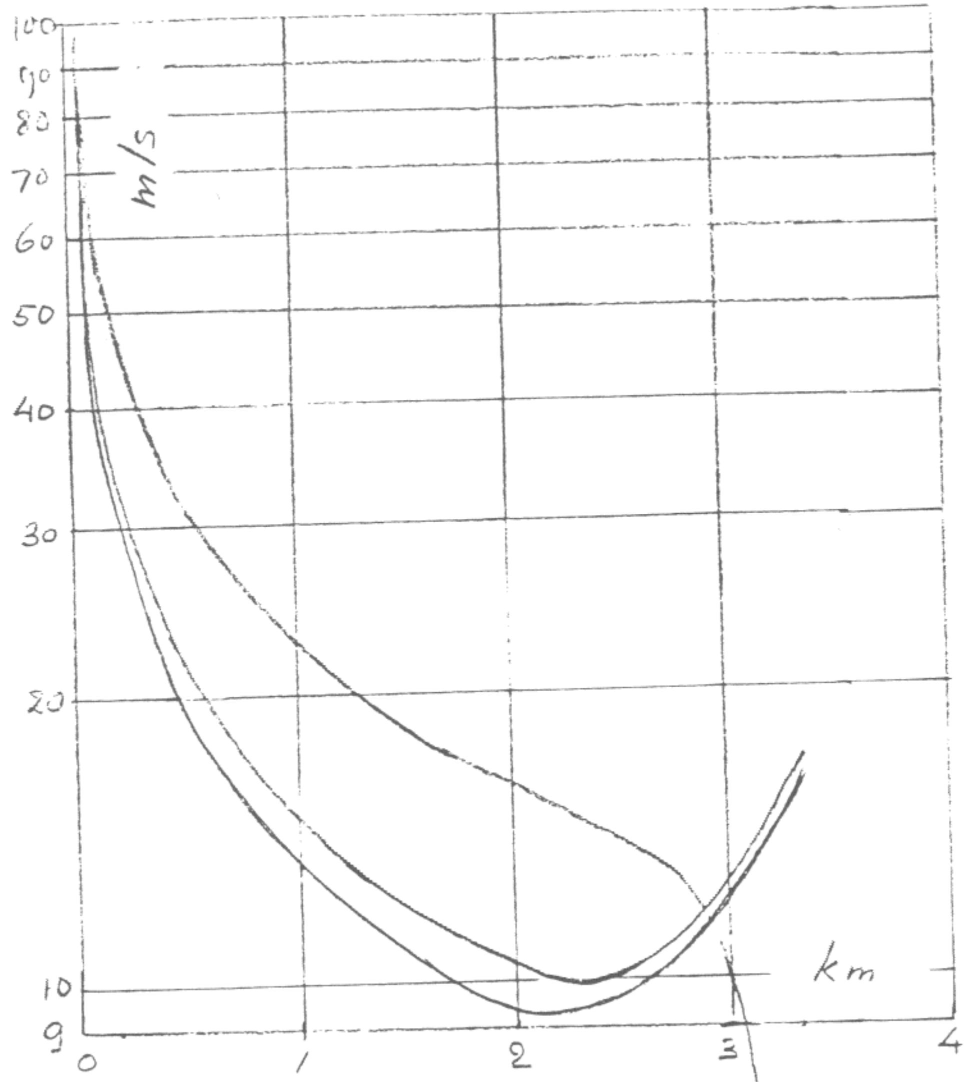

100
90
80
70
60
50
40
30
20
10
9
m/s
km
0
1
2
3
4

FIG 2

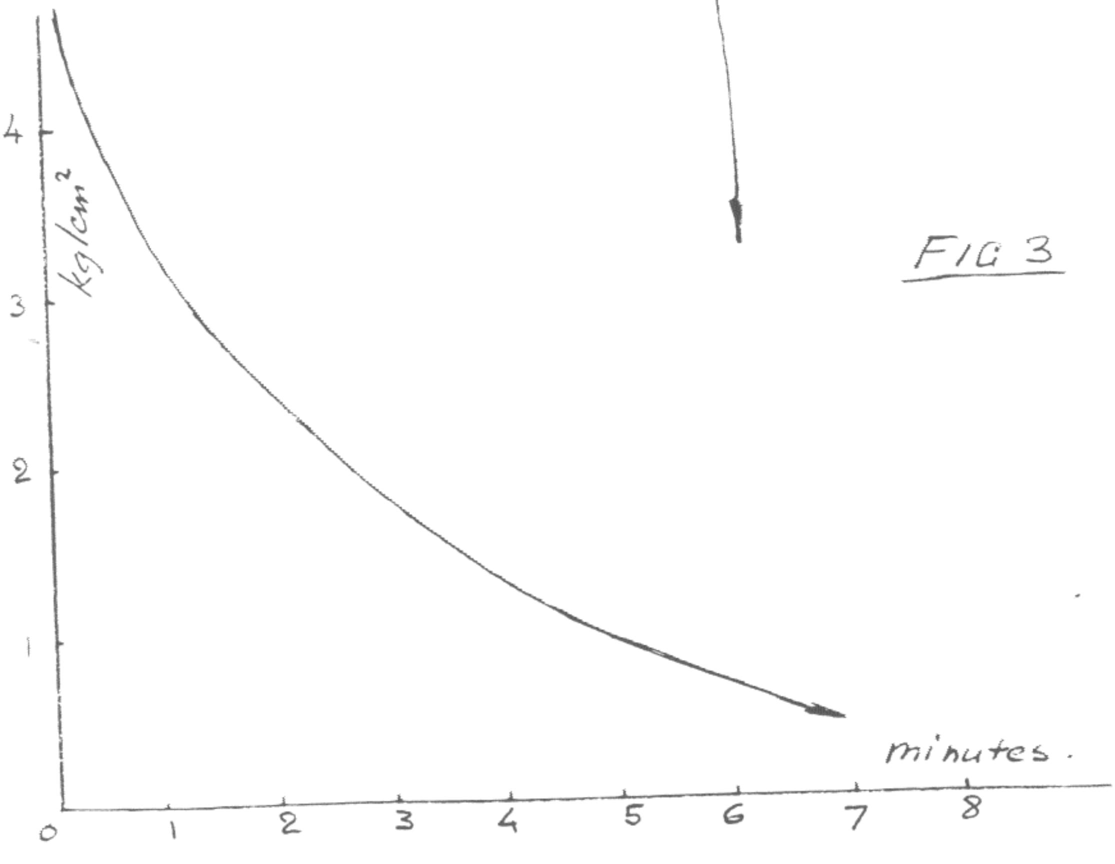

4
3
2
1
kg/cm²
minutes.
0
1
2
3
4
5
6
7
8

FIG 3