SNO-STR-2002-002
INSERTION of the PCS in SNO

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INTRODUCTION

In this document we address the case for putting the proportional counter source (PCS) into SNO. We point out there is a strong physics case for its use by SNO. This case is addressed in the first part of the document. The second part of document addresses the main concern that the Th on the wire will find some way to get off the wire, out of the cartridge, into the main volume of the support structure and from there into the D_2O. In the development of the system, we have experienced the usual teething problems. These problems have been addressed and overcome. Therefore we discuss the problems and detail our solutions to them. We point out here that these problems have been technical: mainly electronic. They have never led to any measurable loss of Th from the PCS. There is no evidence any Th from the PCS has leaked out of the PCS and contaminated the laboratory in Ottawa or the water or the laboratory in Sudbury. We make two points: first that there is a good physics case for inserting the source in SNO and second that the source is safe. In the final section we discuss the details of the deployment of the source in SNO.

For a detailed description of its mechanical design, Monte Carlo simulations and usefulness for the determination of the Th/U backgrounds in SNO, we refer you to our web site

http://www.physics.carleton.ca/~snoman/.
> username: sno_person
> password: theneutrino

The account name and password are the original ones. If you have a problem please let either Ferenc or me know.

PHYSICS MOTIVATION FOR PROPORTIONAL COUNTER CALIBRATION SOURCE PCS

The object of this source is to measure the Th and U background spectra in SNO. These backgrounds are from Thorium and Uranium contaminants in the heavy and light water, the PMT's and the acrylic vessel. The beta-gamma decay of various isotopes in their decay chains produces the electromagnetic energy that is the main low energy background in SNO. The energy from these isotopes produces an exponential "wall" at low energies (1-5 MeV) the tail of which extends into the low energy region of the charged current (CC) and neutral current (NC) spectra of SNO. Therefore the accuracy with which we can measure this tail has a major impact on the accuracy of our determination of the low energy spectra. One big advantage of the source is that it is insensitive to the neutrons produced by the source since it operates in the tagged or triggered mode. This will remove the neutron spectrum from the measured Th/U spectrum.

The various daughters (due to Th/U plating out on detector components and Radon leaching into the detector) in each chain may not be in secular equilibrium, and this makes it important to evaluate the actual contribution of each component in order to get a good estimation of the backgrounds in SNO. This can be done with the source since each of the daughters can be measured individually using it.

It will improve our ability to calculate and measure both the shape and intensity of the background wall, and contribution to the background from photodisintegration of the deuteron by gamma energies exceeding 2.2 MeV.

The source also provides an additional tool for tuning the Monte Carlo. This is important since one never has enough tests of our understanding of the simulation techniques. Providing an additional one is always beneficial.

A list of properties of the source is:

1. Low mass container wall and therefore minimal distortion to the Cherenkov spectrum
2. Triggered or tagged and therefore its contribution can be identified with respect to the rest of the triggers.
3. Its position is well determined in SNO and it can be moved about in the detector to known positions in either the light or heavy water.
4. Small and known size.
5. The source strength is fixed and the signal seen by SNO will have no time variation associated with it.
6. Any source can be put on the wire

The measurements that can be made with the source are:

1. The light water deployment can measure the amount of leakage from the Th/U signals from the source into the heavy water. This can be used to test the fitters with respect to the reconstruction leakage into the D_2O. This is an important factor in determining one of the contributions to the NC backgrounds and how far out in radius we can use the D_2O data.
2. It can be used to determine the shape and absolute intensity of the backgrounds.
3. It can be used to determine the $theta_{ij}$ shape for the Th and U spectra.
4. It can be used to produce source spectra free from neutron contamination since the neutron signal will be out of time with the source.

A comparison of the SNO spectra of a bare point source and the PCS source for ^{228}Th from a Monte Carlo calculation is shown in Figure 1. It shows that the PCS spectrum has only small differences from that of a bare source. One expects that this difference will be easily understood and the PCS can be used to simulate the SNO backgrounds from Th and U. (This picture is to be updated with a high statistics Monte Carlo to give a better picture of the high energy tail)

PCS Simulations and Engineering Run Data:

In Oct 2000 the PCS was deployed at the center of the D_2O for an engineering run. The source on the anode of the PCS was a very low activity, <1 Bq, ^{228}Th source. NIM level logic was set-up so that whenever a beta or alpha was observed in the PCS, SNO was triggered (ext4 of the external trigger inputs) see Fig. 2 for the ext4 triggered NHIT spectra. In the ^{228}Th chain there are also five alpha particles that do not produce Cherenkov light. So that the low energy shoulder in the ext4 triggered NHIT spectrum is due to random ext4 triggers. The second feature in the data is the SNO response to the ^{228}Th beta-gamma Cherenkov spectra that appears at the high NHIT part of the spectrum. The shape of this shoulder must be measured with high statistics so that SNO can determine the fraction of high NHIT Thorium events that leak into the neutrino dataset.

Also shown in the figure is the scaled PCS SNOMAN calculation NHIT >17(dashed) that includes the full PCS geometry and the convolution of the beta-gamma cascades from ^{212}Bi and ^{208}Tl. The dotted line in the figure is for a ^{228}Th point source where the PCS geometry is turned off in SNOMAN. It is seen that the PCS SNOMAN simulation is in agreement with the ext4 triggered PCS data taken last year. We emphasize the data was taken with a 1 Bq source. Our current sources have 200 and 1000 Bq of ^{228}Th on them.

Comparison of Tl and ^{24}Na and the Theta$_{ij}$ Distributions

The document by H. Nguyen and G McGregor (see the analysis log book on Manhattan posted on July 11) presents a Monte Carlo comparison of the ^{208}Tl and ^{24}Na data taken in SNO. The document says the NHIT and theta$_{ij}$ distributions are similar for ^{24}Na and Tl. We would say rather that there are significant differences. The document properly concludes that the distributions can be used to understand how well SNOMAN simulates low energy events. It does <u>not</u> conclude that a good ^{24}Na simulation will lead to a good simulation of the Th/U spectra. Since the Th/U and ^{24}Na have different beta-gamma decays, it does not follow and they do not say that it follows, that a good simulation of ^{24}Na gives a good simulation by SNOMAN for Tl. We suggest the only way to prove this is to measure the Th/U spectra. We further say that the PCS will provide such a measurement. As an example we show the theta$_{ij}$ distribution for Th as simulated in SNOMAN for the PCS and a point source in SNO in Fig.3. To get an idea of the difference between these distributions for the two sources go to the Ngyuyen and McGregor note that shows that their calculated Tl theta$_{ij}$ distribution on the same plot with their calculated ^{24}Na theta$_{ij}$ distribution.

Physics Conclusions:

We conclude that the source will make the following significant contributions

1. It can be used to test the fitters with respect to the reconstruction leakage into the D_2O. A light water deployment can measure the amount of leakage from the Th/U signals from the source into the heavy water. This is an important factor in determining one of the contributions to the NC backgrounds and how far out in radius we can use the D_2O data.
2. It can be used to determine the shape and absolute intensity of the backgrounds.
3. It can be used to determine the theta$_{ij}$ shape for the Th and U spectra.
4. It can be used to produce source spectra free from neutron contamination since the neutron signal will be out of time with the source.

DESIGN FEATURES

First we give a brief description of the Proportional Counter Source (PCS) so that the reader will be able to understand the terms. A drawing of the source with the parts described below is shown in Fig. 4 with the exception of the cover.

The PCS is made up of a proportional counter (PC) in the form of a cartridge, a polycarbonate container (PCC) that houses the PC, a stainless steel support structure (SS), a filling system (FS), a pressure monitoring system (PM), a preamplifier and HV supply system (PA), a cover to protect the last three of the systems from the water and provide the attachment of the PCS to the positioning system (CO) and a monitor module (MM) which houses the electronic equipment to power and monitor the PA and monitor the operation of the system. The important design criteria for each of these systems is described below.

The Proportional Counter Cartridge (PC)

The PC is an independent cylindrical cartridge 1 cm in diameter with thin walls of opaque carbon loaded kapton with an impedance of 1 Mohm/square. The ends of the cartridge are plugged with two end caps of black delrin that support the central wire. These end caps are opaque and the unit is designed to prevent light from the proportional discharge escaping from the cartridge. The wire is strung between the two end caps and crimped to two feed throughs in the end caps.
The following aspects of the design have been specially incorporated to limit the chance of the radioactivity escaping from the counter.

1. Gas access to the cartridge is through a 1 mm hole in the top end cap.
2. Th-228 is electroplated onto the wire over the central 3 mm of the wire. Two PC's have had 200 Bq (PCA) and 1000 Bq (PCD) of ^{228}Th electroplated onto their wires. The electro plating stabilizes the source on the wire and there has been no observed loss from the wire.

The Polycarbonate container (PCC)

The PCC is a polycarbonate tube with a hole down the center to hold the PC. Over the central region its wall has been thinned down to .7 mm to allow the escape to the beta and gamma rays from the source with a minimum energy loss to the particles. The ends are cone-shaped to add strength and they intercept only 4% of the escaping radiation. One end of the tube is closed and the other is attached to the SS and sealed with double o-ring seals.
In order to guarantee the counter is mechanically safe as a container for the radioactivity the following tests have been done.

1. The unit made up of the SS and the PCC have been pressurized to 1000 psig internally and 350 psig externally without failure.
2. They have been subjected to controlled drop tests well beyond anything they would encounter in SNO. For details refer to our web site.

The Support Structure (SS)

The SS has the following characteristics:

1. It is stainless steel.
2. It supports the PC and its PCC on the end of a tube. This tube separates the PC from the main mass of the SS and minimizes the interference of the SS with the emitted radiation.
3. It contains the gas of the PC in a relatively small volume.
4. It provides a support platform on which to mount the electronics (pre-amp, HV feed through).
5. It seals the gas of the PC in its volume.
6. It provides a support for the gas charging and evacuation system.
7. It supports the pressure monitor.

In order to add addition safety against the escape of the radioactivity, all the seals in the SS are double O-ringed except for the HV feed through and the PM attachment.

The Filling system (FS)

The FS is made up three stainless steel pieces: two valves and a quick connect. These three pieces are welded together and welded to the SS. In order to protect the system from releasing radioactivity this system has the following safeguards.

1. In operating mode the gas is double sealed by the two valves and has the third seal of the quick connect.
2. The system is interlocked to prevent the quick connect from being released without the nearest valve being closed.

The Pressure Monitor (PM)

The pressure sensor is type GS Sensors XPM5. The data sheets are given in Appendix 1. The signal from the PM is a 0-100 mV for a pressure change of 150 psia. The output is from a bridge circuit and sent on two separate umbilical lines to the MM on the surface. The details of the MM are given later.

The pressure transducer is composed entirely of titanium and is screwed in by M5 thread into a stainless steel cylinder that has a 1/4" pipe thread. The sensor is sealed to the cylinder by a stainless steel/nitrile gasket. The cylinder is screwed into a boss welded onto the top plate of the SS with the 1/4" pipe thread.
The PM is powered from the same low voltage supply lines as PA. Its signal lines are protected by capacitors and chokes to prevent HV discharges from damaging the circuits on the monitors. See the PA circuit diagram for these protection circuits.

The Preamplifier (PA)

The circuit diagram of the PA is shown in Fig 5. It takes the High Voltage (HV) from the umbilical through a filter network to a HV connector. The PA HV connector plugs into a high voltage feed through in the top plate of the SS. The anode wire and ground of PC are attached to the feed through by a hook-up wires. The signal from the PC to the PA is AC coupled to the PC at the HV connector.

The PA is charge sensitive. Its output is coupled to the HV cable of the umbilical and sent through that cable to the electronics on the deck. The input and output circuits of the preamp are protected by the diode circuits shown on the diagram. A test pulse from a pulse generator is provided to the PA for test purposes and is fed into the input through a 2.2 pf capacitor. The low voltage power to the PA and PM (+/-6 V) are sent down the umbilical and the ground is supplied to the circuit board by the ground on the cable from the pulse generator. These lines are well decoupled to remove any pickup.

The Cover (CO)

The CO is made of stainless steel and bolts to the SS and covers the FS, PM and PA to seal out the water. The CO has a single o-ring seal to the SS. It has double o-ring sealed access port for the umbilical. It also has a conical attachment for the manipulator weight. When the PCS is in the water the CO provides an extra seal against the possibility of activity escaping from the ports in the SS into the water.

The Monitor Module (MM)

The monitor module supplies the low voltage to the PA and the PM. It houses the PM, HV and the rate alarm systems. The circuit diagram for these systems is being drawn and will be included when available.

The PM alarm circuit is made up of an amplifier and comparator. The amplifier multiplies the PM signal by 100 and sends it to the comparator and a front panel connector where it is monitored with a voltmeter. A pressure of 150 psia will give 10 V out. The output from the comparator turns on an open collector transistor used to provide the alarm signal. The voltage output from amplifier is compared by the comparator with a voltage that can be set by a front panel potentiometer on the MM. In this system if the voltage from the PM drops below the preset threshold on the comparator it turns on the transistor. When turned on the transistor initiates an audio alarm in the module and also sends an alarm signal to the SNO slow controls (CMA) system. The sensitivity of this circuit to pressure changes is at the 2% level.

The HV power supply has its own trip output. This trip circuit monitors the current being drawn and will trigger if the current goes above 80 na. This output is also sent to the alarm transistor in the MM. A HV trip will set off the same alarm systems mentioned above.

We have also installed a rate meter circuit in the MM. The PCS rate is sensitive to changes of pressure since the gain on a proportional wire is an exponential function of pressure. Therefore we monitor the mean rate and also trip the alarm system if this rate changes by a variable preset amount. The circuit is now in the test stage and its sensitivity will be measured in the near future.

Safety Measures

In this section we reiterate the precautions built into the PCS in order to guarantee its safe deployment in SNO as well as describe some additional safety measures. The major concern we address here is the danger of the Th on the anode wire leaking into the water.

1. All critical o-ring seals are doubled.
2. The radioactivity is contained in its own cartridge with only a small (1 mm) hole for filling and evacuating the charging gas.
3. The radioactivity is electroplated onto the wire. This makes it entirely solid matter. Rate measurements and searches for Th daughters on the walls give no evidence of the Th leaving the wire. These tests are at the level of a few percent. The pressurized counter has been de-pressurized from its operating pressure to atmospheric pressure by 100 sudden releases through a .2 micron filter. No evidence of ^{228}Th was found on the filter with limits at a few counts.
4. The SS has been tested to 1000 psig internal and 350 psig external pressures. The operating pressure is 50 psia.

5. The operating pressure is such that the pressure difference across the PCC is small. (We are currently operating at a pressure of a few psi above the pressure at the bottom of the vessel)
6. The assembly has been drop tested well beyond the danger level in SNO.
7. The assembly has been leached and no significant amount of Th-228 has been found on it.
8. A bare PC cartridge (i.e. with no PCC around it) with 40 BQ of Th228 on the wire has been leached in UPW and the amount of Th-228 on it was found to be equivalent to the production of 1 photo disintegration neutron every 100 days as an upper limit.
9. The filling and evacuation system has been double protected against any activity getting out of the source with two valves and a quick connect. This system has a fail-safe protection built into it in order to prevent the quick connect from being disconnected without closing the valve. (Drawings to be updated)
10. The alarm system of the High voltage supply is connected to a sonic alarm and to the CMA system to warn us of any loss of high voltage for any reason.
11. The output of the PM is connected to an alarm system that sounds a sonic alert and triggers a CMA alert if there is a drop in pressure in the PCS.
12. There is an alarm system that monitors the rate from the counter. Any drop in pressure will cause the rate to rise and this will trigger the alarm.
13. The source has been run at the temperature of ice water over night to make certain that there is no deleterious effect from its insertion in the SNO water.
14. It has been run sealed in water of a period of 1 week in order make sure there are no unexpected effects of water on the operation of the counter.
15. The system will be charged on the surface and then sealed and taken under ground. It will only be opened on the surface.

Problems with the PCS

Most of the problems with the PCS have centered on the electronics. These problems have been mainly associated with the high voltage system. Since the input and output of the preamp are fed through high voltage capacitors to the high voltage system, if there is a glitch of any sort in the high voltage it will easily destroy the transistors of the preamp. We have also found that it will also destroy the sensitive circuits in the pressure monitor. As a result of these problems, we have made two new preamplifiers with their high voltage as isolated as we can possibly make them from the PA and PM. However, this isolation is not perfect since both the PA and PM use the same low voltage supplies and a large spike in the HV system can overpower the isolation.

Here are my recollections of the problems we have encountered in our attempts to put the PCS in SNO.

The Engineering Run 30 Oct 2000

1. The initial activation method of evaporating the Th-228 onto the wire and covering it with Al by vacuum deposition did not work. Therefore we had to develop the electroplating method.
2. The first preamplifier stopped working during insertion. We don't know why. It was probably due to some discharge in the HV distribution system.

Second insertion attempt

We were preparing to insert the PCS when a cold solder joint opened on the preamp high voltage connector to PC causing an electrical discharge. This destroyed the preamplifier transistors and the pressure monitor readout system.

Third insertion attempt

1. This was halted before insertion when we found an anomalous reading of our pressure sensor in the junction after removing the PCS from the junction. The actual cause of this problem was not determined. (Recently we have associated this with a poor connection of the low voltage supply to the preamplifier.) When the detector was returned to Ottawa, it was found that the sensor and detector were operating properly.
2. Our proposed explanation was that after the discovery of the low pressure reading (probably due to the above mentioned poor low voltage power supply connection) and during the testing of the sensor in the junction, the main valve was accidentally left open and the pressure accidentally released from the counter through the male quick connect. Here, the problem was that the male sex quick connect had been put on the PCS for reasons of space. The pressure could easily be released by touching the end of it. This has since been corrected by replacing the male quick connect with a female quick connect. Now it is impossible to open the quick connect accidentally. It is thought, although impossible to establish, that the opening of this valve was done during the testing of the sensor in the junction. There is some possibility that this occurred in the DCR and this is impossible to establish or refute. Therefore there was a major effort to decontaminate the lab underground.

We have since carried out 100 sudden releases of the full gas charge in both the 200 Bq and 1000 Bq sources through 0.2 micron filters. The filter from the 200 Bq source was counted in an alpha counter and no evidence of ^{228}Th was found on it. This is convincing evidence that even if the gas is catastrophically released in a sudden event, no ^{228}Th is released with it.

Insertion Program

We are proposing a major change to the insertion program of the source into SNO. This is proposed as a result of our recent measurement of the gain stability of the PCS over a period of one week. Fig. 5 shows the variation of the 6 keV gamma ray peak from ^{55}Fe decay as a function of time. Over 8 days of running with the PCD source completely closed, the pressure was constant and the amplitude of the peak dropped only about 7%. This drop is small enough that it is easily compensated for by raising the voltage of the counter or lowering of the threshold of the low level discriminator on the electronics. This has been repeated with the source in water and no effect of the water has been found.

The impact of this on the insertion of the PCS in SNO is that the PCS can be charged well before its insertion and therefore well away from the cavity. It is proposed that this could occur either in the surface building or at Laurentian University. This would make it possible to have the source completely sealed while under ground.

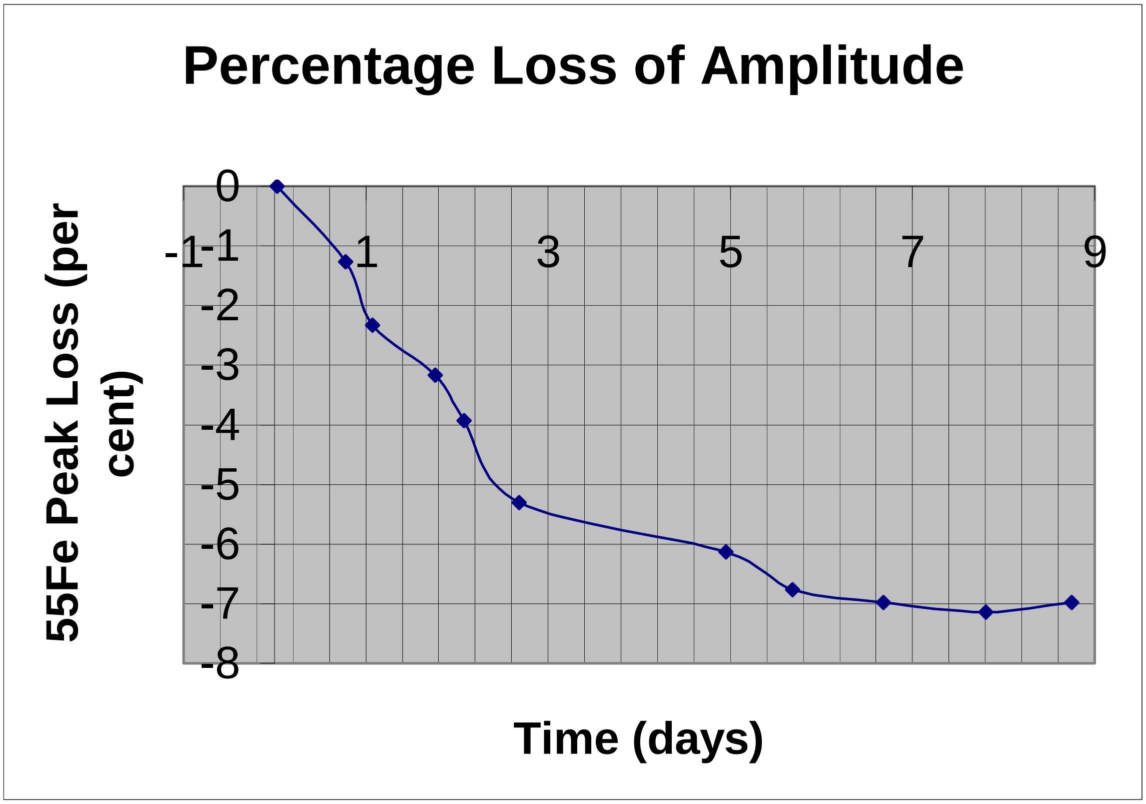


Figure 5. This is a plot of the variation of the amplitude of the 6 keV peak from a ^{55}Fe source in the PCD source with time.

We would propose the following sequence of events for the insertion of the source in SNO.

Preparatory Activities

1. Have PCA and PCD pass the leach test in Ottawa
2. Set up the gas charging system for the PCS at Laurentian University ensuring that all gases from the charging system are exhausted outside the building
3. Evacuate and charge PCA and PCD with the counting gas at Laurentian University on the day before insertion of the PCS in SNO
4. Check the pulse heights of both counters with the Fe source
5. Measure the pressure of both counters after filling
6. Run them in ice water over night
7. Check the pressure and pulse height in the morning before taking it under ground
8. If everything passes these tests take the counters under ground

General Insertion program

Light Water Insertion

Objectives
1. A dry run to debug the detector insertion and electronics systems and the interface of these with the SNO data acquisition system

2. Test the feed through of the PMT beta gamma decays in using the PCD (1000Bq) source in the light water.
3. Measure the response of SNO to Th backgrounds in the light water

Program
1. Insert it close to the equator and run for several hours
2. Move up to a distance close to the PMT’s and take a long run
3. Move to half way between the PMT’s and the AV and take an intermediate run
4. Remove source

This should take about 2 shifts.

Heavy Water Insertion

This is detailed in the web site. The procedures for this and the program are detailed there.

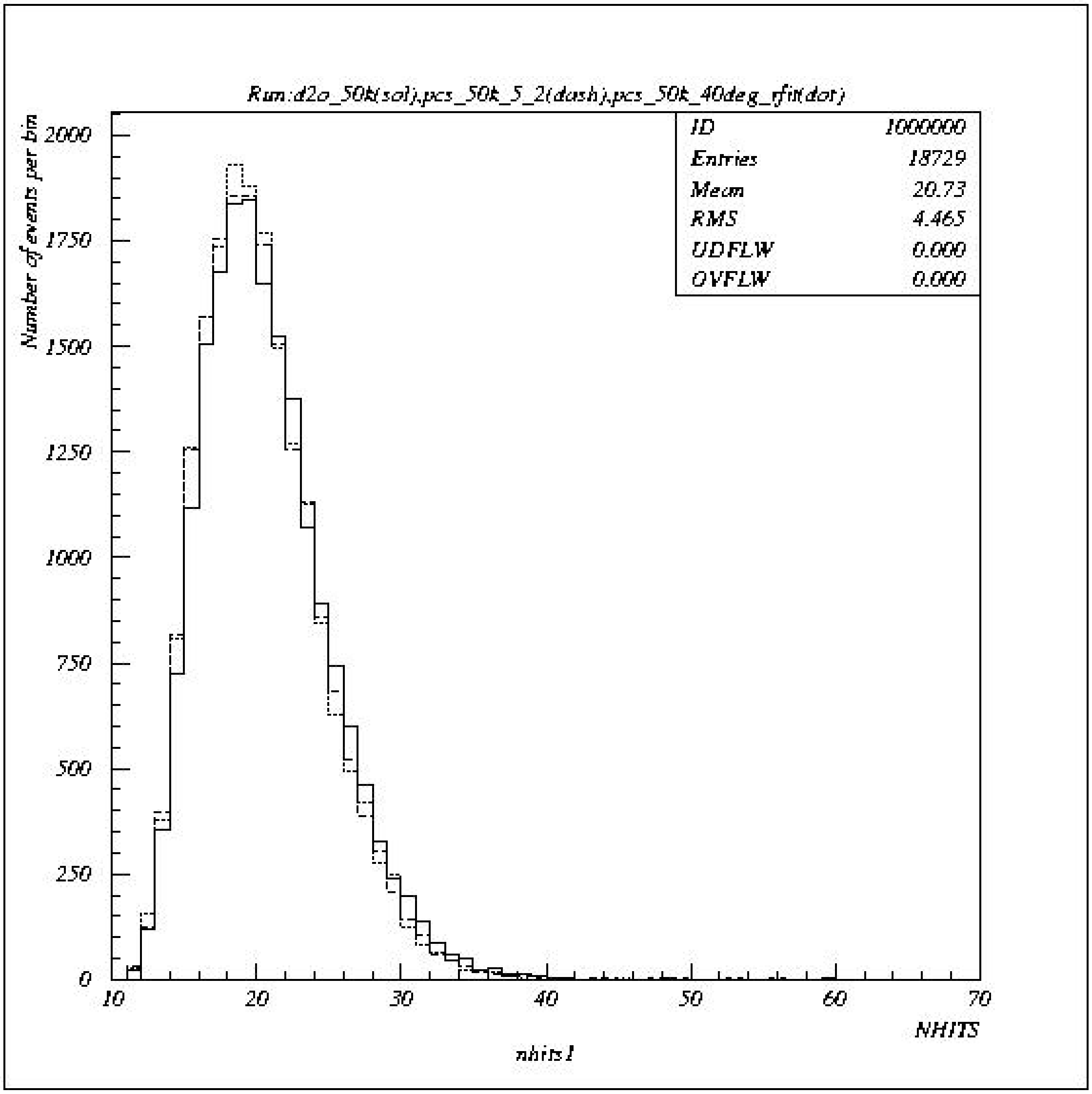


Fig. 1 Comparison using a Monte Carlo simulation of the Nhit spectra in SNO of ^{208}Tl for the PCS (dashed), a bare source (solid) and the PCS data fitted with R<3cm and the beta angle greater than 40 degrees relative to the anode direction (dotted).

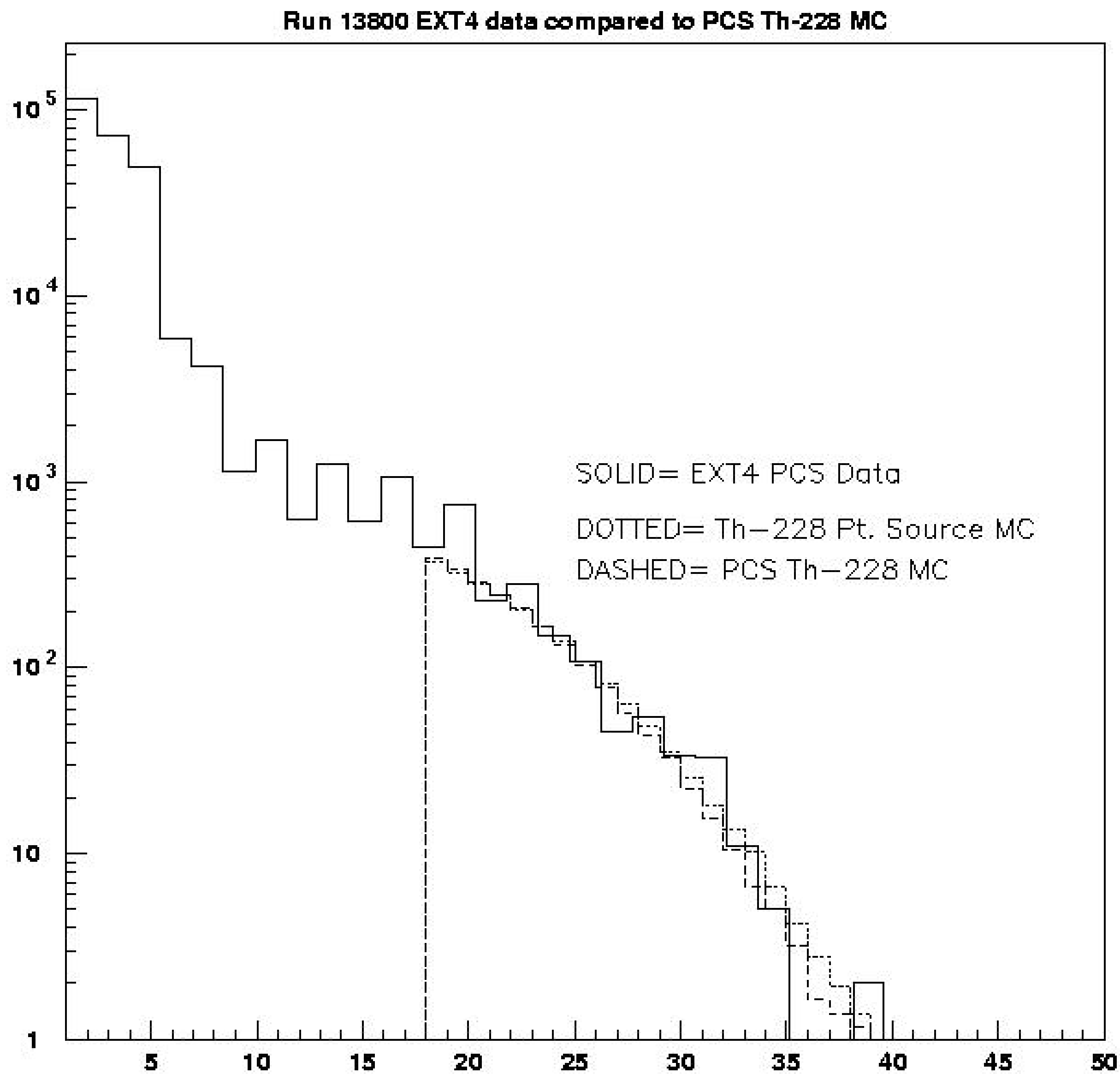


Fig. 2 shows a comparison of Run 13800 (solid) with the Monte Carlo of the source (dashed) and a free source (dotted).

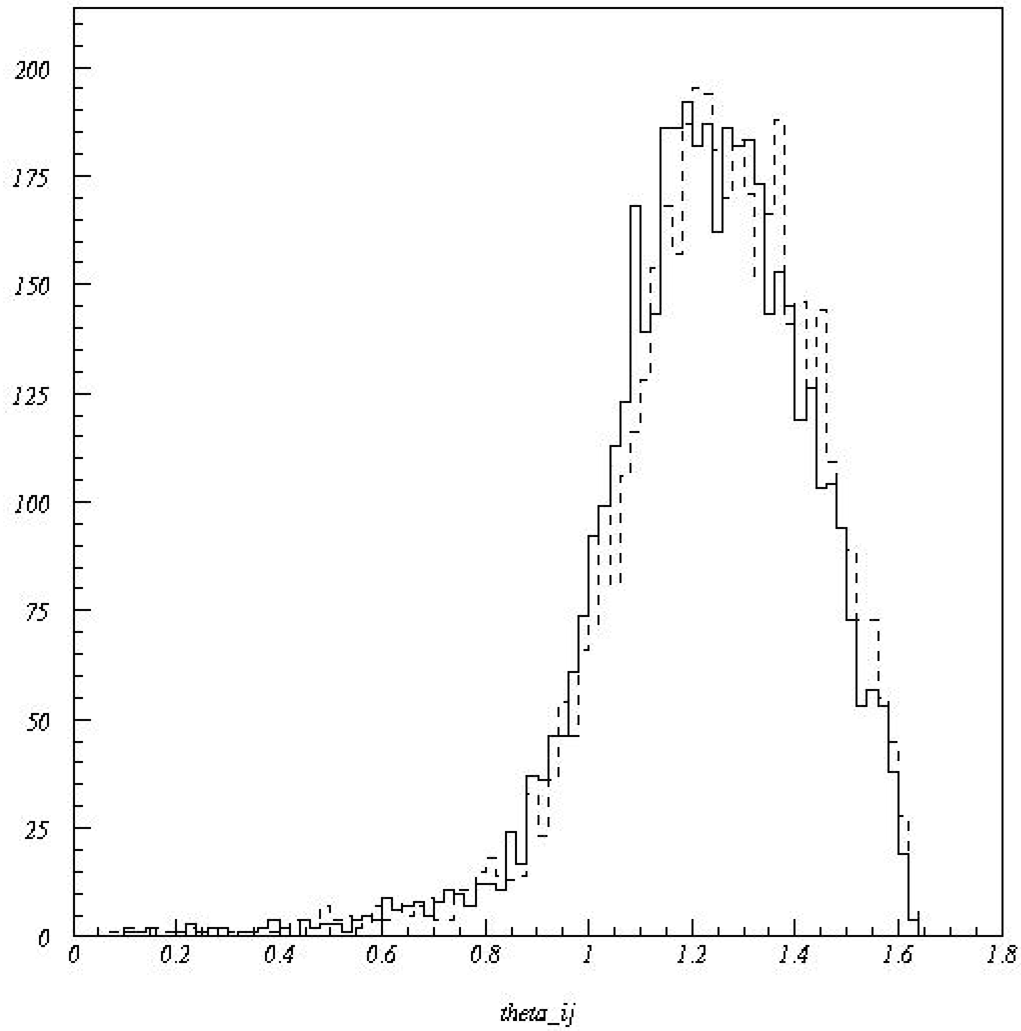


Fig.3 The ^{208}Tl $theta_{ij}$ distribution in the Nhit region 25 –35 for the PCS (solid) compared with that of a point source (dashed) using the Snoman Monte Carlo .

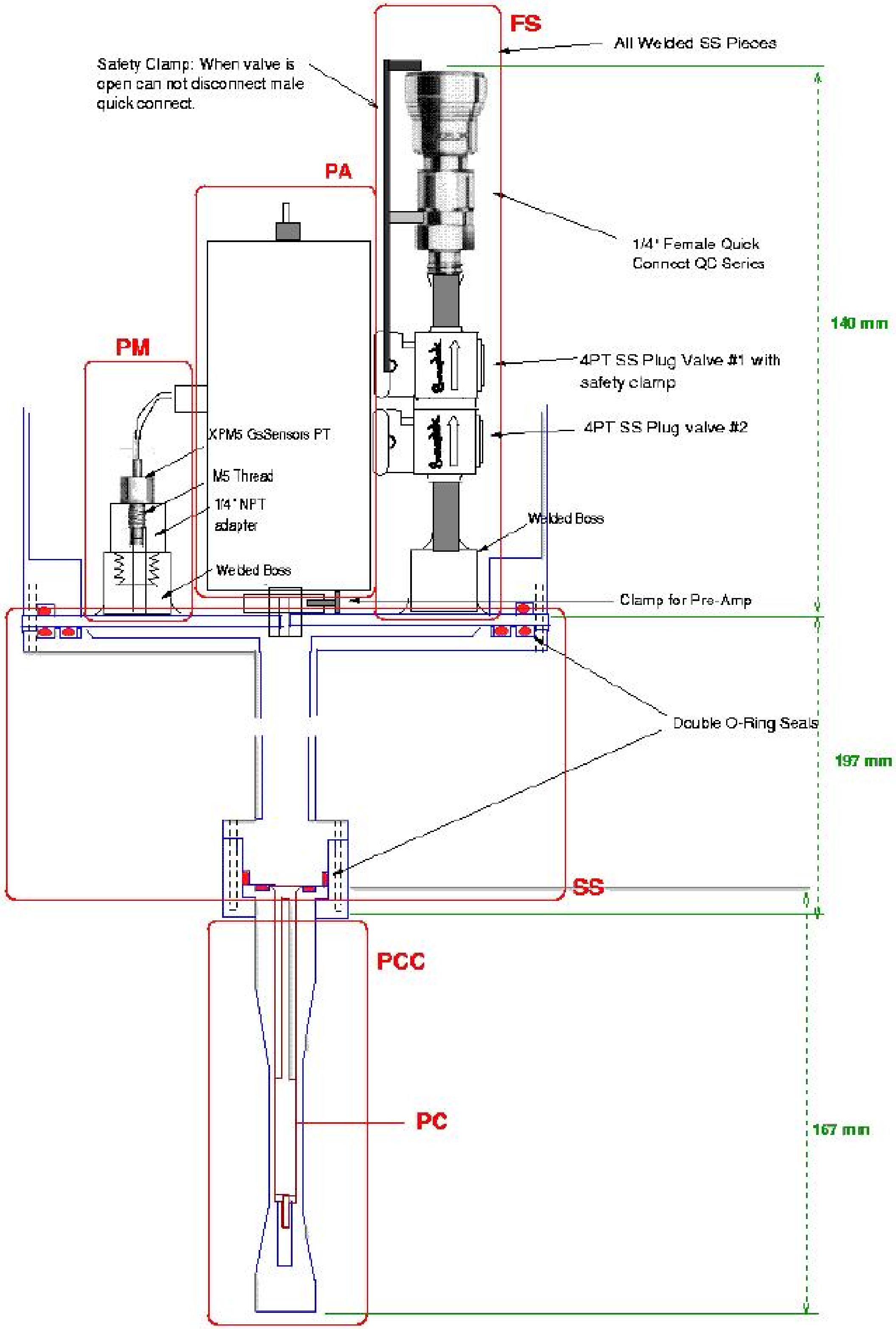


Fig. 4 Drawing of the PCS showing the main components as described in the text.

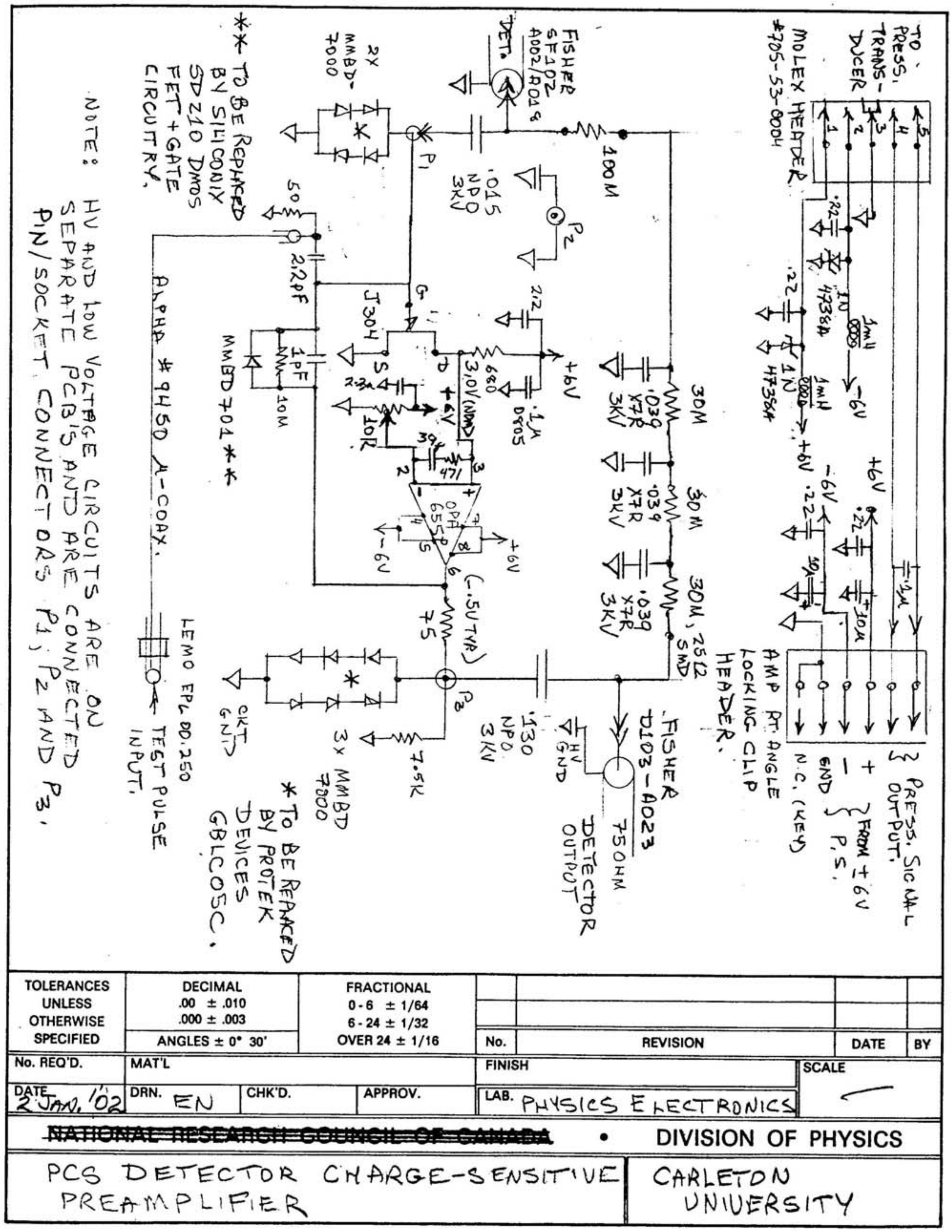


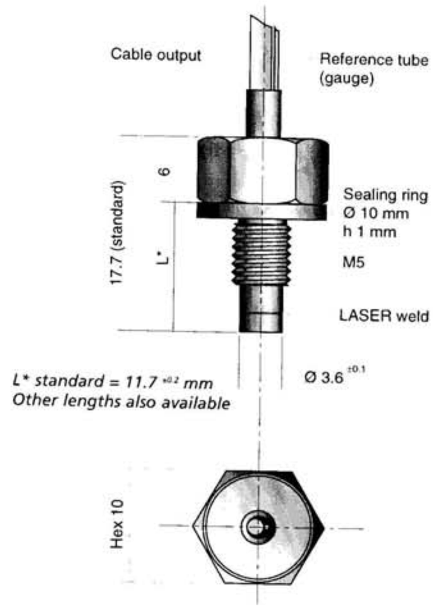
Fig. 5 The circuit diagram of the preamplifier.

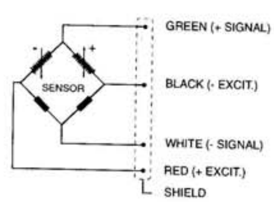
Appendix 1
The PM data sheets

M5 miniature pressure transducer
Ranges 2 bar through 350 bar
Accurate to ±0.25 %
Insensitive to tightening torque
All titanium construction
Flush diaphragm
High natural frequency
Excellent stability

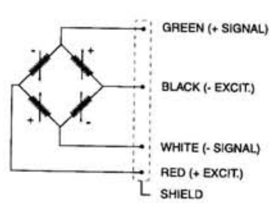
The XPM5 is a miniature, flush membrane pressure transducer with an M5 (or 10-32 UNF on the XP1032) thread. Originally developed for hostile environments, the transducer is constructed entirely from titanium. The XPM5 has a unique mechanical design which renders the transducer insensitive to tightening torque.
The diaphragm is equipped with micromachined silicon gauges bonded to the surface in a Wheatstone bridge configuration. This technology allows a performance and stability which is unrivalled for this type and size of transducer.

Dimensions in mm





Range ≥ 10 bar



Range ≤ 5 bar

GS SENSORS

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07/1999

XPM5

Mechanical specifications

Ranges : 2, 5, 10, 20, 35, 50, 100, 200, 350 bar gauge, sealed gauge or absolute
(30, 75, 150, 300, 500, 750, 1500, 3000, 5000, psi)
Over pressure : 2 x range (no change in specification)
Burst pressure : 5 x range
Media compatibility : fluids compatible with titanium
Natural frequency : from 50 kHz to 400 kHz
Self-centred sealing ring (Nitrile / Stainless Steel)

Electrical specifications

Excitation : 10 Vdc
Sensitivity : 100 mV F. S. (60 mV for 2 bar model) nominal
Input impedance : 1500 Ω (900 Ω minimum for range £ 5 bar)
Output impedance : 800 Ω or less
Zero offset : ±5 % F. S.
Isolation resistance : 100 MΩ at 50 Vdc
Electrical connection : 1 m Teflon cable on standard

Accuracy

Linearity : ±0.25 % F. S. (±0,35 % for ranges £ 10 bar)
Hysteresis : ±0.25 % F. S.
Repeatability : ±0.2 % F. S.

Temperature specifications

Operating temperature range : -40 to +120 °C
Compensated temperature range (CTR) : 0 to 60 °C
Zero shift in CTR : < 2 % F. S. (< 3 % F. S. for 2 bar)
Sensitivity shift in CTR : < 2 % of reading

Torque specification

All ranges : recommended = 5 Nm (generates < 1 % zero and sensitivity shift)
Max torque = 10 Nm

Options

- **HA** • High accuracy - combined non-linearity & hysteresis (CNL & H) : < ±0.25 % F.S. (< ±0.35 % F.S. for ranges £ 10 bar)
- **ZI** • Improved zero shift : < 1.5 % F. S. / 60°C (< 2 % F. S. / 60°C for 2 bar)
- **SI** • Improved sensitivity shift : < 1 % of reading / 60 °C
- **ET** • Extended operating/compensated temperature range : -40 to +150 °C
- **LC** • Custom length 9 to 25 mm
- **EC** • Extra cable length (m)

Ordering format

XPM5 - XXX - X - X

Pressure range in bar

Type
G = Gauge
S = Sealed gauge, A = Absolute

Options
HA, ZI, SI... (any combination)

Example : XPM5-100-G-LC20 = XPM5 100 bar, gauge and custom length L* = 20 mm

GS SENSORS

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