Pressure Analysis for Neutral-Current Detectors

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Abstract

The neutral-current detectors (NCDs) planned for SNO will be subjected to various internal and external pressures during their manufacture and use. The resulting design constraints are considered.

1 Introduction

The NCDs to be deployed in SNO have a diameter (internal) of 5.08 cm, and are made of CVD nickel tubing manufactured in lengths of 200 cm. Counter lengths of 200, 250, and 300 cm are produced by flaring and welding sections together where necessary. Counters are filled with a gas mixture containing ^{3}He and CF_4, and deployed in long strings in the heavy water. At the bottom of the SNO vessel, the absolute pressure is that due to a column of D_2O of height $12 + 6 = 18$ m, plus 1.3 atmospheres of air pressure, for a total of 3.22 atmospheres.

The counter, when evacuated before filling, experiences a net compressive pressure of 1 atmosphere. The gas pressure used in a filled counter is a compromise between the need to obtain good capture probability (high pressure) and the low drift speeds, poor signal-to-noise, and low saturation threshold that characterize high-pressure proportional counters. A total pressure of 2.5 atm absolute has been selected.

2 Failure Mechanisms and Pressures

When the internal pressure exceeds the external, relatively thin-walled counters can contain the gas satisfactorily. This case has been calculated by Doe: a 0.010-inch wall gives a safety margin against bursting of a factor of 35 when the internal pressure is 3.5 atm.

When the internal pressure is less than the external, the tube is at risk of collapse. From the Engineering Handbook [1], the collapse pressure is given by

$$W_c = KE\left(\frac{t}{D}\right)^3$$

where E is the modulus of elasticity, K is a constant that can be read from curves plotted as a function of the ratio of length L to diameter D of the tube (see Fig. 1, t is the wall thickness, and R the radius. When the tube is very long compared to its diameter, the curves asymptotically approach K = 2.1. The tabulated value of E for nickel is 30.5 Mpsi (210 GPa), but Mirotech gives for CVD nickel 25.8 MPsi (178 GPa).

The tubing must be able to withstand one atmosphere external pressure while being pumped out in preparation for filling. The wall thickness of the nickel needs to be minimized (subject to the condition that the tubing not collapse), because that maximizes the efficiency and minimizes backgrounds. For a tube 300 cm in length to withstand an external pressure of 15 psi, a thickness of not less than 0.0130 inches was derived.

At the bottom of the vessel the external pressure of 3.22 atm absolute and the internal pressure of 2.5 atm absolute leave a net compression pressure of 0.72 atm (10.2 psi). Hence a tube that resists collapse during construction in the laboratory has a 30% pressure safety margin in SNO.

3 Measurements

To test the correctness of the assumptions a 2.000-inch inside diameter tube was prepared by Mirotech with wall thickness of 0.0123 inches (Mirotech) to 0.0128 inches (our data). It was sectioned into 2 pieces 40 inches each in length. O-ring piston seals were inserted in each end and the tube pumped slowly down while the pressure was monitored with a Bourdon gauge. One section collapsed at 19.25 inches of Hg, the other at 20.8 inches. A hard vacuum read 30.0 inches on the gauge; the official barometric pressure at UW at the time was 1017 mbar. The three pressures convert to 9.45, 10.22, and 14.78 psi, respectively.

The effective wall thicknesses obtained from the collapse pressures are 0.01117 inches and 0.01147 inches. That these are slightly less than the mechanically measured values probably is a manifestation of the surface roughness.

To withstand 14.73 psi a wall thickness of 0.01295 inches would be required, plus a maximum of 0.0017 inches derived from our measurements above, or 0.01465 inches.

We therefore specified a minimum wall thickness of 0.015 inches (and a maximum of 0.018 inches), and were reasonably confident that very few would collapse during assembly.

A 300-cm counter with a wall thickness of 0.014 inches (mass 513 g/m) survived initial testing, but failed at the time of evacuation before filling, likely a result of the removal of approximately 0.001 inches during electropolishing and etching.

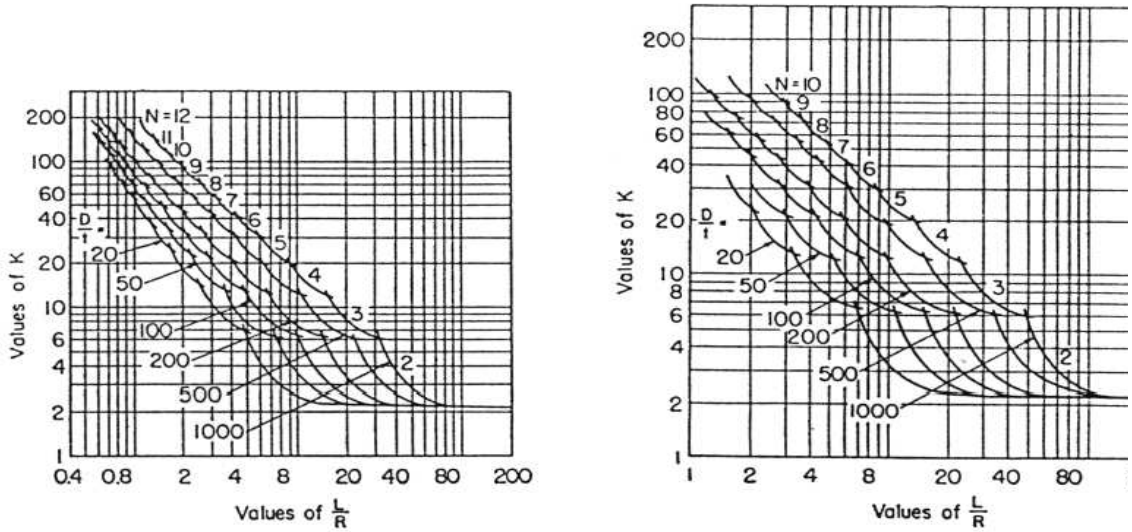

Fig. 63. Radial external pressure with simply supported edges.

Fig. 64. Radial external pressure fixed edges.

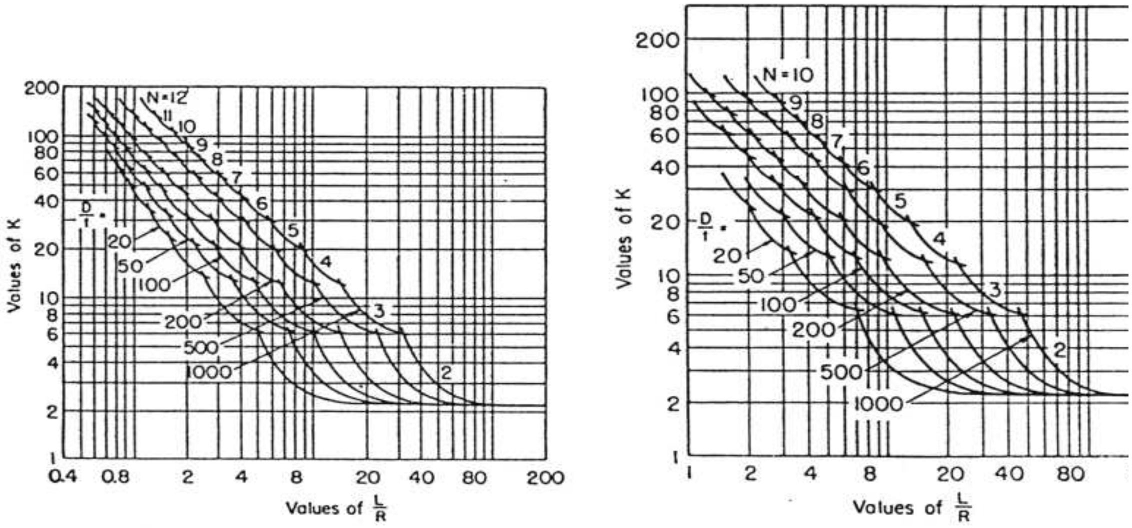

Fig. 65. Radial and end external pressure with simply supported edges.

Fig. 66. Radial and end external press with fixed edges.

Figure 1: Sturm's K-factor for calculating collapse pressure of tubing.

4 Delay-line Capsules

The delay-line capsules at the bottom of each string are 6.3 inches in length and filled with atmospheric pressure (1.3 atm at the 6800-foot level) air. While the pressure differential is higher, the shortness of the tube permits thinner wall material to be used. The graph in Fig. 2 shows the thickness as a function of collapse pressure for two different lengths of tubing.

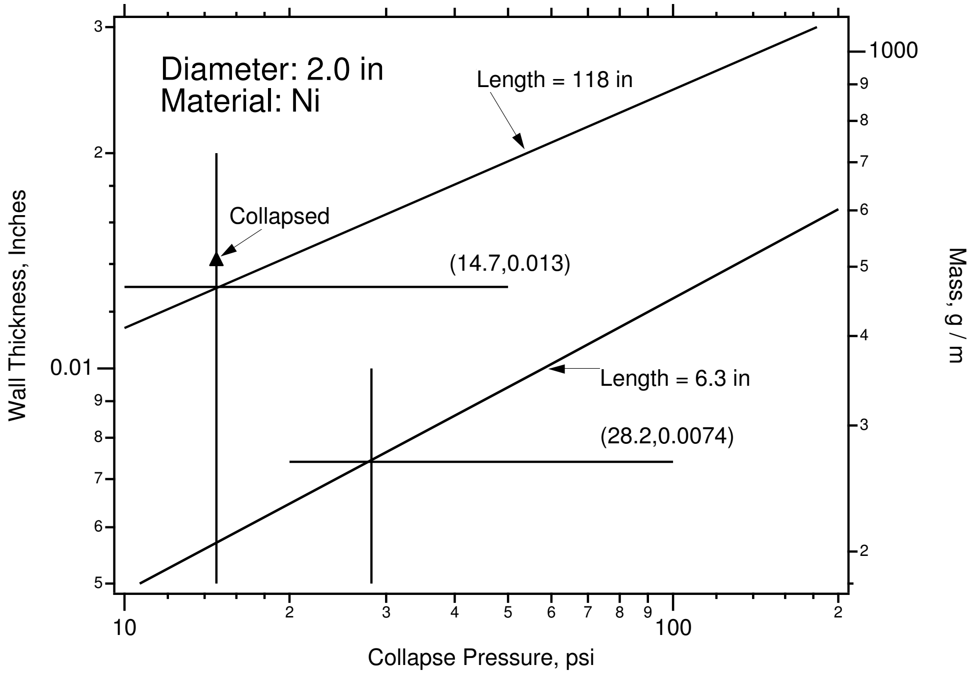

Figure 2: Collapse pressure *vs* thickness for 16-cm and 300-cm lengths of nickel tubing.

References

[1] The Engineering Handbook (McGraw-Hill, New York, 1967); R.G. Sturm, Univ. Illinois Experimental Station Bulletin 12, Nov. 11, 1941.

[2] Mirotech Inc., Toronto, Canada.