A PRESSURIZED MULTIWIRE PROPORTIONAL CHAMBER FOR NEUTRON IMAGING

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SUMMARY

A pressurizable neutron-sensitive multi-wire proportional chamber has been constructed to test the effect of increased gas density on image resolution. The chamber has dimensions of 25 cm x 25 cm and is pressurizable to 4 atm. With a single-plate converter the thermal-neutron detection efficiency was 6.3% for gadolinium and 2.3% for boron-10. For a four-fold increase in chamber pressure the overall resolution improved more than a factor of two for boron, but relatively little for gadolinium. The effects of cathode biasing is also discussed.

INTRODUCTION

Earlier work on neutron imaging[1,2] using a multiwire proportional chamber in conjunction with a neutron converter showed that the spatial resolution obtainable was limited by the track length of the conversion products in the chamber gas. Conversion product track length limited the resolution of a boron-10 converter to approximately 2.5 millimeters and appeared to make gadolinium, the preferred converter for photographic thermal neutron radiographic imaging, altogether unsuitable. Characteristics of these two converters are shown in Table 1. Gadolinium has the largest thermal neutron capture cross section of any naturally occurring element providing extremely high efficiency and high source definition. The maximum range of its film sensitizing capture products in photographic emulsion is less than 50 μm leading to the observed high resolution.

TABLE 1

Characteristics of Gd and ^{10}B Converters

Converter	Conversion Products (% yield)	Maximum range in converter (g/cm^2)	Maximum Range in Ar at 1 atm
^{10}B	1.5 MeV α (100%)	8.28x10^{-4}†	
	0.8 MeV ^{7} Li(100%)		1 cm
Gd	70 KeV e$^-$ (44%)		
	30 KeV e$^-$ (28%)	1.1x10^{-2}*	4 cm

*See Ref. 3, †See Ref. 4

We have constructed a pressurizable wire chamber in order to test the suitability of gadolinium as a converter, as well as to study generally the effects on resolution of decreasing the reaction product track lengths.

CHAMBER CHARACTERISTICS

The construction of the chamber has been previously described in ref. 2. The chamber has an active area of 25 cm x 25 cm. The outer pressure vessel is constructed with side walls of 7.5 cm aluminum channel and faces of 1.25-cm-thick-high-tensile-strength aluminum (7075) plate. The front face was milled out to a depth of 0.75 cm over the sensitive area of the chamber. The vessel was designed and tested for an operating pressure of 45 psig (4 atm). The pressure is monitored with a Statham strain gage type pressure transducer, accurate to 0.5% full scale. The back face of the chamber proper can be fitted with interchangeable converter plates. The front face is covered with a thin sheet of aluminum foil to prevent ionization track electrons produced in the outer volume from drifting into the sensitive chamber region. An ^{55}Fe x-ray source is deposited in one corner of the foil for gain normalization when the pressure is changed. The chamber is being operated at a proportional gain of approximately 7000. The voltage needed to maintain constant gain is shown in fig. 1.

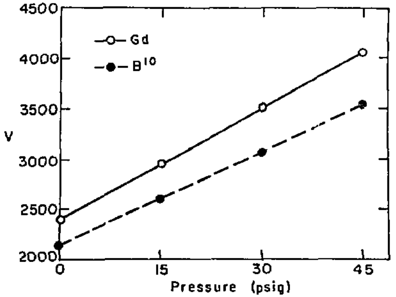

Fig. 1. Anode voltage vs. chamber pressure for constant gain.

CHAMBER PERFORMANCE

If all the reaction products had a straight line range equal to the *maximum range*, then the efficiency is given by, $\varepsilon = 1/2(1+1/R\Sigma(\exp(-R\Sigma)-1))$ where Σ equals the macroscopic cross section for *neutron absorption* in the converter, and R is the maximum range of the reaction products in the converter. A plot of this function is shown *in fig. 2*, together with the measured values. The measured thermal neutron efficiencies for the Gd and ^{10}B single plate converters were 6.3% and 2.3%, respectively, having the same ratio as the calculated values, but less than 1/2 of their absolute magnitude. *Efficiencies* were unaffected by pressure; however the n-γ discrimination was. In the energy range that gives the best spatial resolution the Cd ratio decreased by a factor of four when the pressure was changed from 1 to 4 atm. (cadmium ratio is used in the experimental sense- as the ratio of (countrate unshielded/countrate shielded with .5mm Cd) The variation with pressure is a measure of the chamber's n-γ discrimination and not the quality of the thermal neutron beam from the reactor). The n-γ discrimination decrease with pressure is *due both* to the increase in the macroscopic cross section for gamma rays and to the increase in the effective track length and therefore the signal size from photo-and-compton electrons.

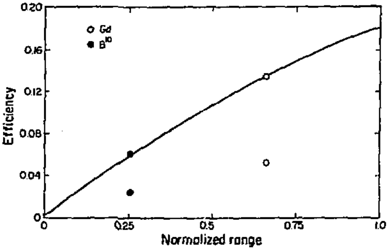

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Fig. 2. Maximum converter efficiency as a function of $R\Sigma$ (see text). The points off the curve are the measured values.

The resolution of the chamber was measured by calculating the modulation transfer function (MTF). This was done in two ways. *One using the line spread function* (LSF), and the other by taking the Fourier transform of a bar pattern that covered the whole chamber. *The latter method yields only* the odd multiples of the fundamental frequency, but it gives the response over the whole chamber, *as opposed to just a small limited area as* the LSF does. The MTF's from the bar patterns were slightly lower due to the averaging of *the chamber response* over the active area

Fig. 3 shows the MTF's for the Gd and ^{10}B converters at 1 and 4 atm. There is a 30% improvement for *the Gd in going* from 1 to 4 atm, and a greater improvement, 110%, for the ^{10}B converter, based on the increase in the "cutoff frequency". *(The modulation* transfer function can usually be fitted by a function of the form $\exp(-(w/wc)^n)$ with n a number between 1 and 2, and wc the "cutoff frequency"[5]. The MTF for ^{10}B at 1 atm is greater than that for Gd at 4 atm, even though the quoted ranges are equal. *But* the electron ranges are not as definite as those for an alpha particle. The numbers quoted (calculated from ref. 3) are for a *mean range*, with a significant number of electrons having a range greater than that value.

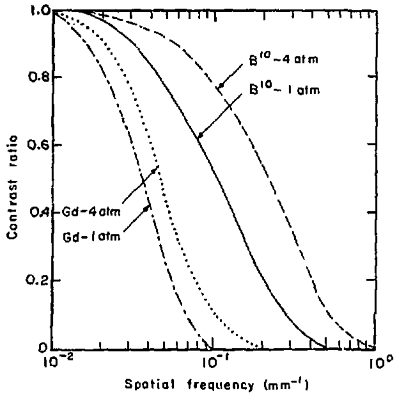

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Fig. 3. MTF's for the Gd and ^{10}B converters at 1 and 4 atm.

It is possible to apply voltage to the two cathode planes of the chamber. Figs. 4-7 show the effect of bias on the resolution. For the longer range particles negative bias improves resolution significantly. For an event at a given point in the converter, the reaction product can emerge at a distance from that point, up to a maximum distance equal to the range of *the reaction product* in the converter material. It then travels through the gas until it either comes to rest or travels completely through *the active volume. The effect* of a positive bias is to insure collection of that portion of the ionization electrons produced in the *region between the converter* and cathode planes. Inclusion of these electrons increases pulse amplitudes and overall detection efficiency. *Because* these electrons are produced closer to the point of emergence of the capture product they carry more precise position information *than those* produced between the cathode planes.

The effect of a negative bias is to largely *reject those electrons produced* in the region between the converter and cathode, thereby reducing the efficiency for detection of reaction products *emitted* at large angles. Because the rejected particles are primarily those emitted farthest from the interaction point, there is also an *image sharpening effect* associated with negative bias.

In general, if the range of reaction products is *very short then* positive cathode bias was expected to increase the efficiency and resolution. When the range of the reaction products is long *compared* to the converter-cathode separation then a negative bias *will* improve resolution with only a small adverse effect on efficiency. *The observed* results are consistent with

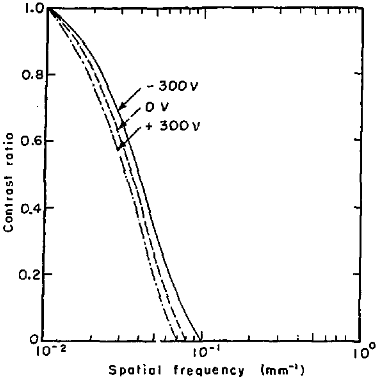

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Fig. 4. MTF for Gd at 1 atm with the cathodes biased at 0V., +300 V., and -300 V.

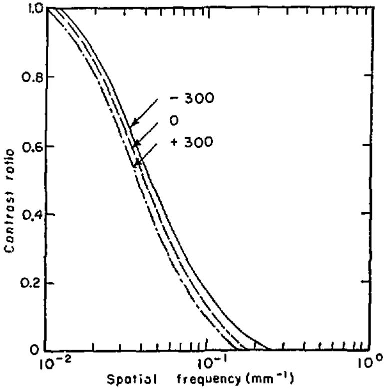

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Fig. 5. MTF for Gd at 4 atm with the cathodes biased at 0 V., +300 V. and -300 V.

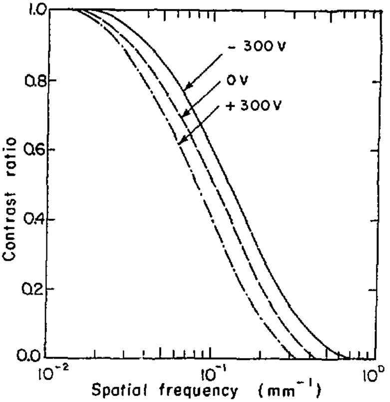

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Fig. 6. MTF for ^{10}B at 1 atm with the cathodes baised at 0 V., +300 V. and -300 V.

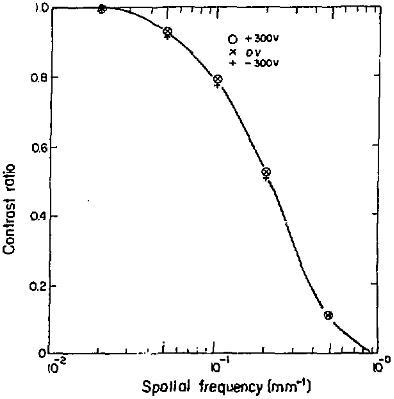

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Fig. 7. MTF for ^{10}B at 4 atm with the cathodes biased at 0 V., +300 V. and -300 V.

expectations. The negative bias produces a significant improvement in resolution, equivalent to an increase in pressure of 1 1/2 atm. This improvement is accompained by a 15% reduction in efficiency. This is also the case with boron at 1 atm.

At 4 atm however, the average capture product range becomes comparable to the converter-cathode spacing. The competing image sharpening effects seemingly cancel each other out, giving no net observable effects as a function of cathode bias.

Improved resolution in the object radiogram (fig. 8) over earlier pictures at 1 atm^2 is not readily evident to the eye; however, the improved resolution does evidence itself in other ways. Flaws in the converter screen not previously noticeable are now prominent. The boron converter is made by embedding fine boron powder in double-faced-pressure-sensitive tape that is applied in strips to a thin aluminum plate. The edges of the strip (width of .5 cm) appear in the background. Also the images of the chamber anode wires, not seen by us before in neutron imaging, are observable.

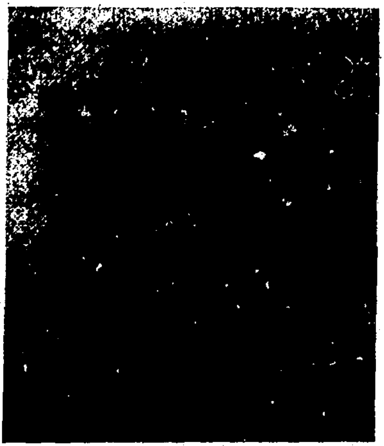

Fig. 8. Radiograph of the front end of an electric drill with a 1/4" nylon cap screw in the chuck.

DISCUSSION

Pressurizing the neutron sensitive wire chamber to 4 atm improves the resolution, but not by the hoped for factor of four. The Gd converter, although having almost three times the efficiency of boron, could not approach the boron resolution. In a solid detector (i.e. photographic emulsion) the ranges of the boron and gadolinium reaction products are both negligibly small and the ultimate resolution is determined by the source (i. e. converter) thickness; hence the superiority of Gd in photographic radiography. Here the predominant determinant of resolution is the range of the reaction products in the gas, and the resolution characteristics are reversed. Where reaction product ranges in the chamber gas are long compared to the cathode-converter spacing, applying a negative bias to the cathode improves resolution, but at the expense of decreased efficiency. As the range of the reaction products decreases one would expect a positive bias to give significant improvement in resolution and efficiency, however this limiting condition is not reached event with ^{10}B at 4 atm.

A collimating converter such as is used in a positron camera might offer more image sharpening characteristics. It is planned to investigate the performance of such a collimator and its effects on n-γ discrimination, efficiency, and resolution.

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