Boron-lined neutron detectors with gamma discrimination for reactor applications

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Neutron sensitive detectors capable of discriminating against gamma background have been indigenously developed for reactor applications. A boron-10 lined proportional counter with 3.5 cps/nv counting sensitivity and a boron-10 lined gamma compensated neutron ion chamber with a current sensitivity of 11fA/nv have been developed for the reactor start up and intermediate range instrumentation, respectively. The detectors have all-welded high-purity aluminium construction and integral mineral-insulated cable assembly. Explosion-welded SS-aluminium clad material has been used as interface between the aluminium body of the detector and the ceramic-metal insulators. The counter has gas filling of argon and carbon dioxide at 20 cm Hg. It has 190 mg of enriched boron-10 coating and can be used over a neutron flux range of 0.1 nv to 10^5 nv. The gamma compensated ion chamber has hydrogen filling at 10 psi pressure. Performance tests in typical neutron and gamma fields show that the chambers can tolerate gamma background up to 1000 r/h and over 100 °C of ambient temperature.

In reactor instrumentation, neutron detectors provide on-line information about reactor power. While the signal from these devices is mainly due to neutrons, some signal is also generated by external gamma radiation. A fraction of the gamma radiation emitted by fission products after the fission event introduces some error in the signal which is not indicative of instantaneous reactor power. The Electronics Division has developed neutron sensitive ion chambers for reactor applications using 92% enriched boron-10 coating on the electrodes. At power level operation where these chambers are employed, the neutron flux is sufficiently high and this error can be neglected. However, at start up and intermediate range operation, interference due to gamma background requires to be minimised.

The present paper describes the development of boron-lined pulse counters for start up instrumentation and the compensated boron-lined ion chambers with volume gamma compensation for intermediate and power range operation. While pulse-height discrimination eliminates the gamma signal in the former, gamma current is electrically subtracted in the latter case.

Boron-10 lined proportional counter

Counters with boron as the sensing element operate on the ^{10}B (n, α) reaction. Boron-lined proportional counters (Fig. 1) developed at the Electronics Division consist of a cylindrical tube with its inner wall coated with elemental boron enriched to 92% ^{10}B isotope with a thickness of 0.75 mg/cm^2. A 25μ diameter tungsten wire, stretched at the centre of this cathode along its axis, acts as the anode. The sensitive volume is filled with argon (95%) and carbon dioxide (5%) gas mixture at 20 cm Hg pressure. The reaction products ionise the gas and as the electrons are accelerated to the anode wire, the charge multiplication occurs. Since the Q value of the ^{10}B (n, α) reaction is greater than 2 MeV, neutron induced pulses can easily be distinguished from noise and gamma pulses. Although, proportional counters of comparable dimensions with BF₃ gas-filling have greater neutron sensitivity, ^{10}B proportional counters can operate in higher gamma background at greater ambient temperature. There is a wider choice of filling gas and the counters require lower operating voltage.

![Fig. 1—Schematic diagram of B-10 lined proportional counter](image-url)
The wire laying and gas-filling operations have been carried out in the Solid State Physics Division, BARC. Table I gives the main specifications of the counter.

The counter has an all-welded high purity aluminium construction. Electrical connection to the anode is provided by means of a high purity ceramic-metal feed-through insulator whose SS component was welded to the aluminium body of the counter with the help of a SS-aluminium explosion welded end-plate obtained from ERDL, Pune (Fig. 2). The detector has an integral assembly of coaxial mineral insulated cable that can withstand high-radiation high temperature environment. A coaxial Amphenol type connector is mounted on the cold end of the cable. Similar counters with lower counting sensitivity have also been constructed out of the SS material for neutron area monitoring applications in health physics.

Performance tests—The counters were tested in a thermal neutron flux of 6000 nV in the Radiation Standards and Instrumentation Division, BARC. The counter output signal was connected to a unity gain charge sensitive preamplifier, linear amplifier with a shaping time of 500 ns, voltage discriminator and a scalar/timer. Integral bias curves (Fig. 3) show that the counter has a sensitivity of 3.5 cps/nV. The curve for the 0.8 cps/nV sensitivity SS counter is shown for comparison. Fig. 4 shows the corresponding voltage plateaus. The aluminium counter was tested for neutron sensitivity in gamma background levels varying up to 1000 r/h. The results are shown in Fig. 5. There was negligible effect on the sensitivity due to an ambient temperature of 100°C (Fig. 6).

Results—The present counter has adequate sensitivity that can measure neutron flux levels of the order of 0.1 nV at the start up range. It can withstand a gamma background of 1000 r/h with 30% reduction.

Table I—Main specifications of boron-lined proportional counter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall dimensions</td>
<td>34 x 300 mm</td>
</tr>
<tr>
<td>Boron content</td>
<td>92% enriched 10B 190 mg</td>
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<tr>
<td>Construction material</td>
<td>1S Aluminium and SS-Al clad plate</td>
</tr>
<tr>
<td>Insulation</td>
<td>High purity alumina ceramic</td>
</tr>
<tr>
<td>Gas filling</td>
<td>Argon (95%) + carbon dioxide (5%) at 20 cm Hg</td>
</tr>
<tr>
<td>Integral cable assembly</td>
<td>3 mm dia coaxial m.i. cable with Inconel 600 sheath and conductor alumina insulation 5 m long.</td>
</tr>
</tbody>
</table>

![Fig. 2](image-url) Neutron detector with explosion welded end-plate

![Fig. 3](image-url) Integral bias curves of B-10 counters

![Fig. 4](image-url) Voltage plateaus of B-10 counters
in sensitivity. Counters of this type are presently under development for start up instrumentation for the Fast Breeder Test Reactor at Kalpakkam.

**Gamma compensated boron-10 lined ionisation chamber**

Gamma compensated boron lined d.c. ion chambers are used in reactor instrumentation in the intermediate range operations. While the upper flux limit of the start up counters is about $10^6$ nV, the lower limit of the d.c. ion chambers is about $10^5$ nV. Gamma compensated ion chambers provide the required overlap in neutron flux between the start up and power range. The sensitive volume of the compensated ion chamber (Fig. 7) consists of two independent sections in which voltages of opposite polarity are applied. The inner volume is sensitive to gamma radiation while the outer one gives rise to a current due to neutrons as well as gamma rays. Gamma compensation factor is given by $(I_{ng} - I_{gg}) / I_{ng}$ where $I_{ng}$ and $I_{gg}$ refer to the gamma induced currents in the outer and inner volumes respectively. The net current is a measure of the neutron flux.

The compensated ion chamber has an all-welded high purity aluminium construction with integral mineral insulated cable assembly. Enriched boron-10 (92%) is coated on the outer wall of the signal electrode with a thickness of 0.75 mg/cm$^2$.

The electrode configuration was designed to avoid unsaturated regions by keeping the length of the three electrodes equal with the help of high purity alumina spacers. The 120 ml sensitive volume is filled with hydrogen gas at 10 psi pressure. The chamber end-plate was fashioned out of SS-aluminium explosion welded clad material. High purity aluminium construction minimises long-term induced activity in the chamber material. The use of integral m.i. cables makes the detector assembly impervious to moisture ingress. Table 2 gives the main specifications of the gamma compensated boron-lined ion chamber.
Table 2—Main specifications of gamma compensated boron-lined ion chamber

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall dimensions</td>
<td>$80 \times 330$ mm</td>
</tr>
<tr>
<td>Boron content</td>
<td>$92%$ enriched $^{10}$B $350$ mg</td>
</tr>
<tr>
<td>Construction material</td>
<td>1S Aluminium and SS-Al clad plate</td>
</tr>
<tr>
<td>Insulation</td>
<td>High purity alumina ceramic</td>
</tr>
<tr>
<td>Gas filling</td>
<td>Hydrogen at 10 psi</td>
</tr>
<tr>
<td>Integral cable assembly</td>
<td>3mm dia coaxial m.i cables with Inconel 600 sheath and conductor alumina insulation 10 m long (3 nos)</td>
</tr>
</tbody>
</table>

The chamber was tested at the cobalt-60 teletherapy facility in the Radiation Standards and Instrumentation Division, BARC, in an exposure rate of 1900 R/h, to estimate the uncompensated gamma sensitivity and the compensation ratio. The detector was heated up to 150 °C and brought back to room temperature with no observable change in performance during tests conducted before and after the heating cycle while checking its tolerance to high temperatures.

The detector was installed in the thermal column of Apsara reactor, at BARC, under a neutron flux of $10^8$ nV and a gamma background of 500 R/h. The flux was estimated by foil activation and the gamma field was measured with the help of a calibrated thimble type in-core ion chamber. The detector was also tested at the Fast Breeder Test Reactor at Kalpakkam at various power levels varying from 10 KWt to 10.2 MWt. Fig. 8 shows the saturation characteristics.

Results—The chamber has an uncompensated gamma sensitivity of 3 pNR/h and the average compensation factor is 6%. The chamber has a neutron sensitivity of $11 \text{ fA/nv}$. In a neutron flux of $10^5 \text{nV}$ the chamber needs $+75 \text{V}$ for saturation and $-20 \text{V}$ for the compensating section for a gamma background of 500 R/h. At 10.2 MWt power level at FBTR, the chamber requires less than $200 \text{V}$ for currents of the order of $10^{-7} \text{A}$. There is negligible change in the signal when the negative voltage is changed from $-50 \text{ V}$ to $-200 \text{ V}$ during the tests that were carried out at 10.2 MWt.

Conclusions

Indigenous development of neutron detectors, capable of adequate discrimination against high gamma background, has been carried out for reactor safety and control instrumentation. The detectors have a rugged construction impervious to moisture ingress. Integral m.i. cable assembly makes them capable of withstanding high radiation and temperature environments. The detectors will be subjected to long-term tests at various reactor locations.

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References