Inexpensive solid state radiation detector

Karen Aplin[1], Peter Hastings[1], Giles Harrison[2] and Keri Nicoll[2]
[1] Physics Department, University of Oxford, Keble Road, Oxford OX1 3RH UK
[2] Department of Meteorology, University of Reading, Earley Gate, Reading RG6 6BB UK

1. Abstract
Traditional technologies for environmental radioactivity measurement such as Geiger counters are relatively expensive and can be difficult to obtain (e.g. there was a worldwide shortage after the 2011 Fukushima incident). They also require a high voltage supply (100-1000V) and only provide a simple particle count rate.

Here we present a low cost (€100), miniaturised (5x5 cm) detector based on solid state technology. It runs at low voltage (from 9V), low current (a few tens of mA) and can interface with a mobile phone or computer via Bluetooth or USB. Unlike other types of solid state radiation detector, it does not need to be cooled. It is capable of simple discrimination between different radioactivity types and energies.

2. Operating principle
The radiation detector uses a 1cm^2 PiN type diode. Energetic particles ionise the depletion layer inside the detector and cause a pulse of current. The height of the pulse is usually proportional to energy.

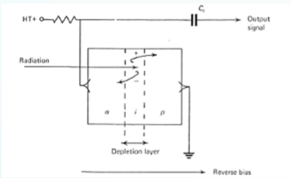

Fig 1 The PiN diode as a radiation detector (Tait, 1980)

Although the operating principle is simple, carefully designed electromagnetic screening and signal conditioning circuitry are needed to keep the device's cost and size down. This work has been partially motivated by the poor performance of other similar devices currently on the market.

3. Device description

Fig 2 Device block diagram

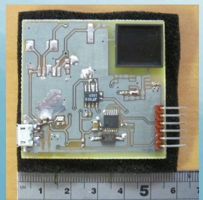

Fig 3 Prototype device

Fig 4 Testing with a radioactive source

4. Expected response
The radiation detector can, in principle, respond to all types of ionising radiation. In practice, some types of low-energy particle are excluded by the sensor enclosure or the noise threshold of the signal conditioning circuitry. The predicted response is shown in Table 1.

Type and origin of particle	Expected response	Detected?	Energy info?
Alphas, betas	Cannot penetrate sensor enclosure	✖	✖
Low-energy gammas (<100 keV) or X rays	Probably below detector noise floor	✖	✖
Energetic gammas (>100 keV)	Detected inefficiently via Compton scattering	✔	✔
Energetic particles, e.g. from cosmic rays or solar storms	Detected efficiently by ionisation if >1 MeV	✔	✔

Table 1 Expected response of PiN detector to different types of particle

In summary, the detector is expected to
- Count and give energy information for gamma radiation and high-energy ionising particles such as protons
- Count very high-energy ionising particles such as cosmic ray muons

5A. Testing – energy response
The detector was tested with three radioactive sources, each emitting characteristic gamma rays. To reduce the complication associated with ^{22}Na emitting two gammas of different energies (Table 2), the detector was placed under 12mm of lead, which removes about 45% of the 0.511MeV gammas (e.g. Knoll, 2010).

Radioactive source	Characteristic gamma energies (MeV)
Cobalt-60	1.17, 1.32
Sodium-22	0.511, 1.275
Caesium-137	0.661

Table 2 Gamma-ray emissions from radioactive sources

Fig 5 shows that the detector can resolve different gamma energies. The error in the ^{22}Na point is from the contribution of 0.511 MeV gammas. This contribution could be straightforwardly removed by using a different source or slightly modifying the experiment.

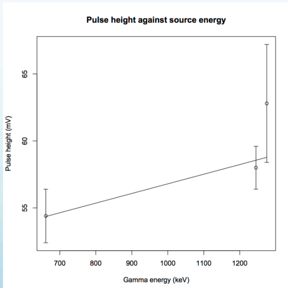

Fig 5 Median pulse heights against source energy. An average ^{60}Co energy of 1.25 MeV has been assumed, and the 0.511 MeV contribution from ^{22}Na ignored. Error bars are two standard errors.

5B. Testing – response to different particles
To compare the response to gamma rays versus cosmic rays, the detector was tested in a lead castle, Fig 6. The lead excludes all gamma radiation and only lets energetic cosmic ray particles reach the detector.

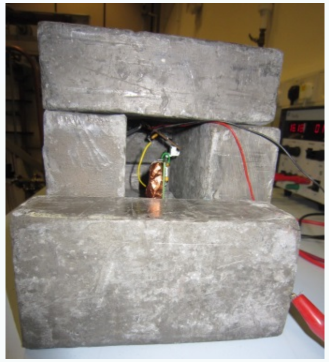

Fig 6 Testing in lead castle to exclude background gamma radiation

- The lead castle makes little difference to the background count rate or pulse height
- The detector is relatively insensitive to background gamma radiation (otherwise there would be a bigger difference between measurements inside and outside the lead box)
- Gammas are detected as a tail of big pulses compared to the muons which are "minimum ionising particles", only depositing a tiny fraction of their energy in the detector.

6. Conclusions
- Inexpensive (€100), small, low-power (<40 mA) PiN diode detector can respond to the full range of radioactivity levels from background natural radiation, up to much higher decay rates.
- Can resolve different gamma energies
- Data can be sent to a mobile phone or computer (via USB or Bluetooth) or written to an SD card. Powered via USB or battery.
- Potential users include
  - Environmental scientists – a wide range of applications
  - First responders e.g. fire brigades who want to check an area is radiation safe
  - School and educational
- Commercial and technical development is ongoing

Acknowledgements
Funded by the UK Science and Technology Facilities Council (Impact Accelerator Account). KAN is partially supported by the UK Natural Environment Research Council (Impact Accelerator Account).

References
Knoll G.E., (2010) *Radiation Detection and Measurement*, 4th edition, Wiley
Tait W.H., (1980) *Radiation Detection*, Butterworths