Radioactive Material Safety Data Sheet

December 16, 2019

PXXISET001-CR003770

1 Description of Source

The source *PXXISET001-CR003770* is a proton irradiated Si chip with a rectangular surface area of about $2 \times 2\,\mathrm{cm}^2$ and a thickness of $400\,\mu$m attached to a $100-150\,\mu$m thick Si sensor. It has been exposed to a fluence of up to $\sim 2\times10^{16}\,\mathrm{p/cm^2}$ of 24 GeV protons in October 2018. Some of the elements used inside the chip have been activated by the protons and therefore it is now a source of β and γ radiation.

2 Isotopes

The main radio-isotopes inside the chip are ~ 6.0 kBq ^{7}Be, ~ 36 kBq ^{22}Na, ~ 1.6 kBq ^{46}Sc, ~ 14 kBq ^{54}Mn, ~ 1.3 kBq ^{56}Co, ~ 19 kBq ^{57}Co, ~ 3.9 kBq ^{58}Co, ~ 2.8 kBq ^{60}Co, ~ 2.6 kBq ^{65}Zn, and ~ 1.0 kBq ^{75}Se (on 16 December 2019).

- ^{7}Be deacys by electron capture with a half life of $\tau = 53$ days and a 10.4% probability of emitting a 0.47 MeV photon.
- ^{22}Na deacys by β^+ decay emitting photons, electrons and positrons with a half life of $\tau = 2.6$ years. The maximum β^+ energy is 2.84 MeV but with a probability of only 0.06%. The main β^+ decay with a probability of 89.84% has a maximum energy of 0.55 MeV The average β^+ energy is 0.217 MeV. The monoenergetic electrons are very low in energy and don't play a role for the dosimetry. The maximum energy of emitted γ radiation is 1.27 MeV with typical γ energies of 1.27 MeV and 0.511 MeV. The average γ energy is 0.78 MeV.
- ^{46}Sc decays by β^- decay emitting photons, electrons and positrons with a half life of $\tau = 83.8$ days. The maximum β^- energy is 1.48 MeV and the maximum gamma energy is at 2.01 MeV.
- ^{54}Mn decays by electron capture with a half life of $\tau = 312.7$ days emitting photons and electrons. The electron energies are below 5 keV while the maximum energy of emitted γ radiation is 0.83 MeV.
- ^{56}Co decays by β^+ decay emitting photons, electrons and positrons with a half life of $\tau = 77$ days. The maximum β^+ energy is 1.46 MeV and the mono-energetic electrons are all below 0.14 MeV and the maximim gamma radiation energy is 3.55 MeV.
- ^{57}Co decays by electron capture with a half life of $\tau = 272$ days emitting photons and electrons. The mono-energetic electrons are all below 0.14 MeV. The maximum energy of emitted γ radiation is 0.69 MeV.
- ^{58}Co decays by β^+ decay with a half life of $\tau = 70.86$ days emitting photons, electrons and positrons. The maximum β^+ energy is 1.50 MeV while energies of monoenergetic electrons are below 0.01 MeV. The maximum γ energy is 1.67 MeV.
- ^{60}Co is an emitter of β and γ irradiation with a half life of $\tau = 5.2$ years. The maximum β energy is 1.49 MeV; the average β energy is 0.10 MeV. The maximum energy of emitted γ radiation is 1.33 MeV. The average γ energy is 1.25 MeV.
- ^{65}Zn is an emitter of β^+ and γ irradiation with a half life of $\tau = 244.4$ days. The maximum β^+ energy is 0.33 MeV; the average β^+ energy is 0.14 MeV. The maximum energy of emitted γ radiation is 1.12 MeV.
- ^{75}Se decays by electron capture with a half life of $\tau = 120$ days emitting photons and electrons. The mono-energetic electrons are all below 0.14 MeV. The maximum energy of emitted γ radiation is 0.40 MeV.

The main activity from all isotopes together stems from the γ-radiation which goes up to 3.55 MeV in energy and averages at 0.66 MeV.

3 Radiation Dose Rates

The γ radiation is not shielded by the chip itself nor by the attached sensor. Directly on top of the chip the γ dose rate is 1.5 mSv/h. The β^+ and electron emissions are largely shielded by the chip (for the radiation below) and the attached sensor (for the radiation above). Hot areas remain the chip edges on all sides and the sensor-free regions on top where the bond pads are located. In these regions the radiation levels can reach 4.5 mSv/h. In 1 cm distance from the chip the γ radiation dose rate reduces to 290 μSv/h and drops quadratically with distance beyond. Figure 1 shows a simulation of the expected radiation levels in the vicinity of the chip.

4 Protective Measures

The β radiation can be fully shielded by 1.5 g/cm^2 of light material (glass, plastic, or similar). Assuming a density of 1.5 g/cm^3 this would correspond to 10.0 mm of required shielding to block all β and electron emissions. A rubber glove with thickness 0.7 mm reduces 95% of the β and electron induced irradiation dose. To achieve the same 95% attenuation for the γ induced irradiation dose a 4.8 cm thick lead layer would be needed.

5 Handling Instructions

The chip have to be carried in a plexi-glass box whenever it is transferred from one place to another. 0.7 mm thick rubber gloves and protective goggles need to be worn when handling the chip. Workstations have to be equipped with plexi-glass shields of 3.5 mm thickness. Assuming a distance of 0.5 m from the chip behind such a plexi-glass screen (or equivalent) will result in a full body dose rate of 0.08 μSv/h.

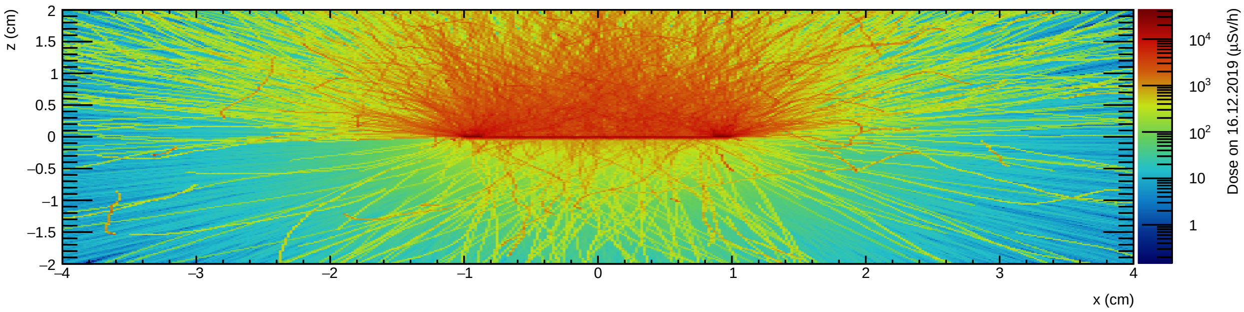

Figure 1: Simulated dose rate in air in μSv/h for a chip with $\sim$ 6.0 kBq ^{7}Be, $\sim$ 36 kBq ^{22}Na, $\sim$ 1.6 kBq ^{46}Sc, $\sim$ 14 kBq ^{54}Mn, $\sim$ 1.3 kBq ^{56}Co, $\sim$ 19 kBq ^{57}Co, $\sim$ 3.9 kBq ^{58}Co, $\sim$ 2.8 kBq ^{60}Co, $\sim$ 2.6 kBq ^{65}Zn, and $\sim$ 1.0 kBq ^{75}Se. The radioactivity is assumed to come uniformly from the chip surface which is covered by Au bump bonds and a 150 μm thick Si sensor except for the last 1.3 mm on the $\pm x$ sides of the chip where the Bond Pads are. The plot shows a side view from the chip with radiation levels in the center of the chip in the not shown y dimension.

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