The effect of protons on the performance of swept-charge devices

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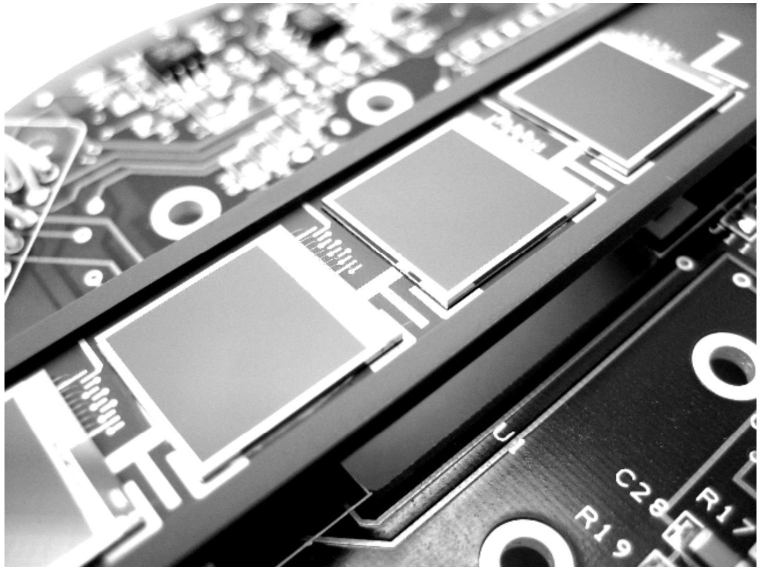
Presentation Overview

- The swept-charge device (SCD)
- The Chandrayaan-1 X-ray Spectrometer (C1XS)
- Space radiation environment modelling
- Proton irradiation studies
- Conclusions



The Swept-Charge Device

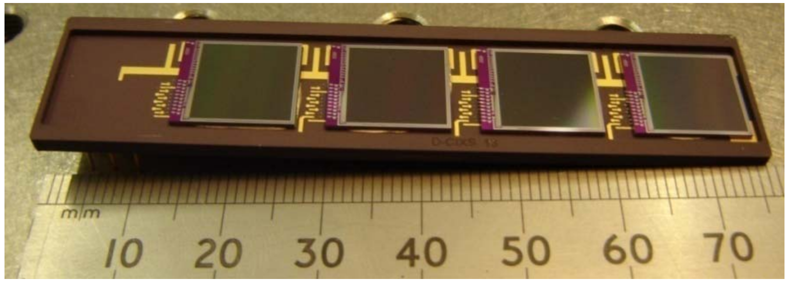
- Developed by **e2v technologies** with funding from **PPARC (now STFC)** and the **DTI** under the **IMPACT** programme

- Specifically for X-ray fluorescence analysis
  - depletion depth ~40 – 45 µm
  - X-ray count rate up to 10 kHz

- Manufactured using conventional CCD techniques

- Large detection area of 1.1 cm^2

- Near Fano-limited spectroscopy at -15 ^oC, a temperature that is easily achievable using a TEC

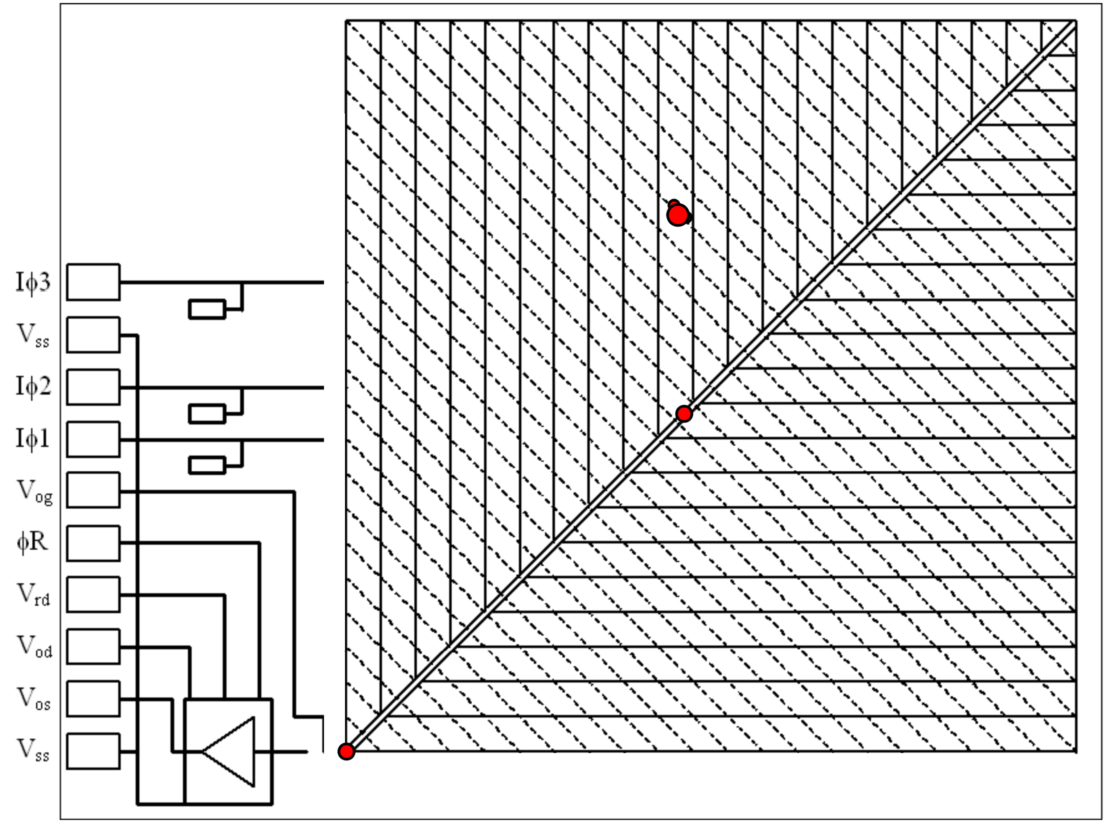


Modular design with 4 devices on one ceramic package

The Swept-Charge Device

- Active area is covered with 1725 diagonal electrodes with the isolation channels in the underlying silicon arranged in a herringbone structure

- The pitch of the channel stops is 25 µm

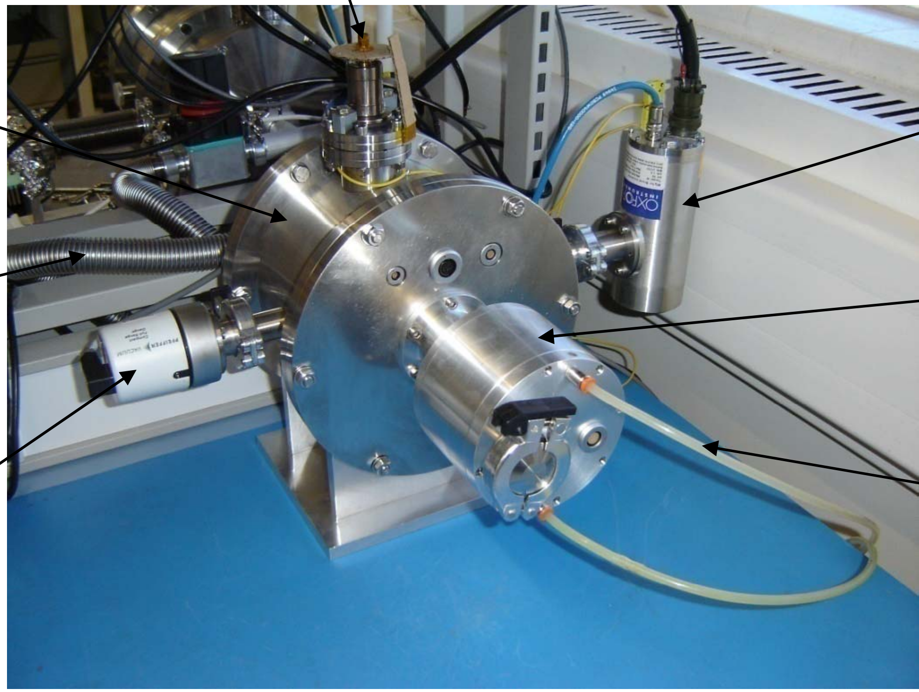


Linear output of 575 ‘pixels’

↑

Measured X-ray charge

SCD Test Facility



- ^{55}Fe source used to provide Mn-Kα X-rays
- Oxford Instruments X-ray tube used to provide other calibration lines by secondary fluorescence (Mg, Al, Cu, Si and rock samples)

SCD Test Facility

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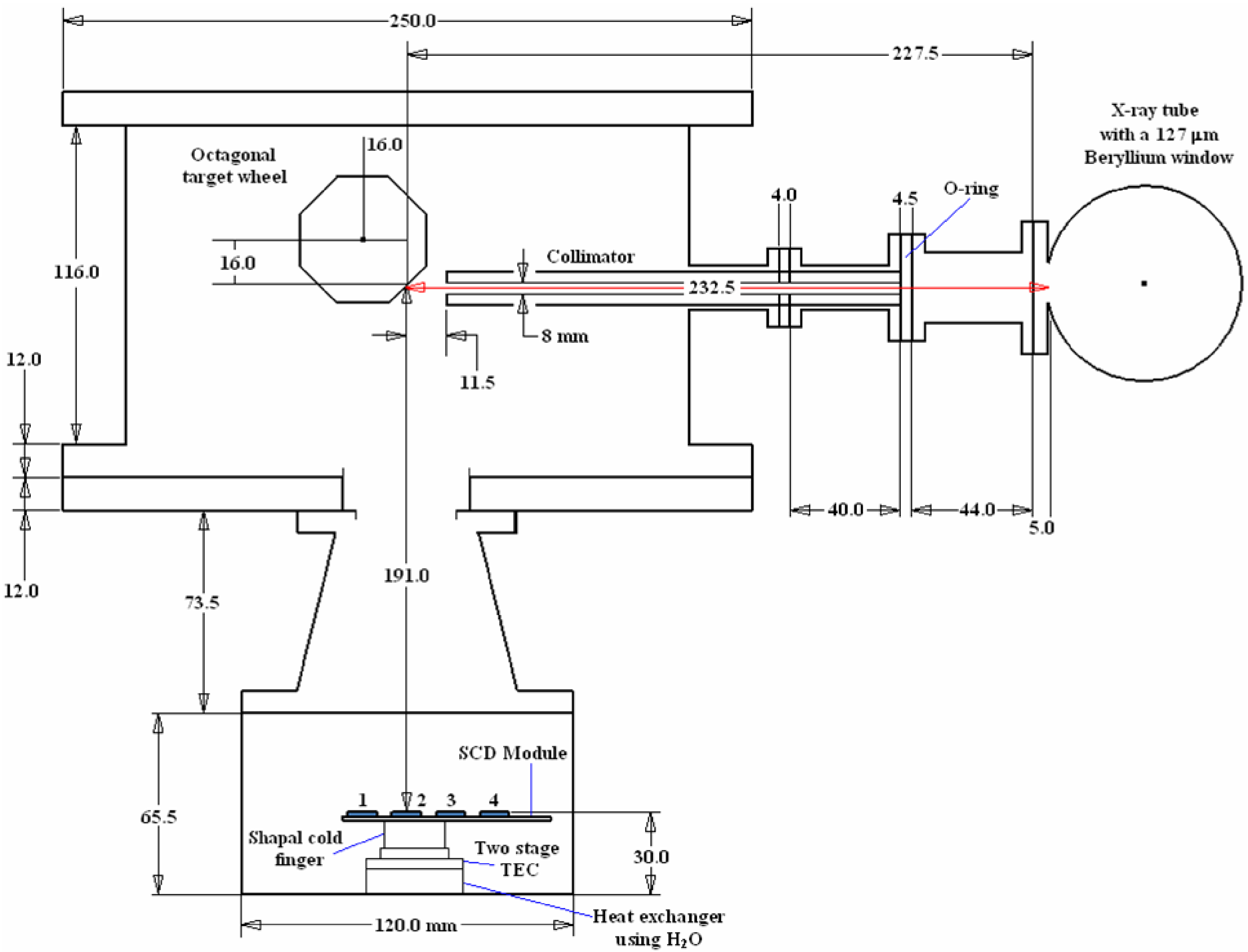


Operational Modes

- Mode 1
  - **resets the charge packets per sample**
  - produces an 'image' similar to that produced by a CCD
- Mode 2
  - **charge packets progressively sampled**
  - 10 ms delay between successive line readouts

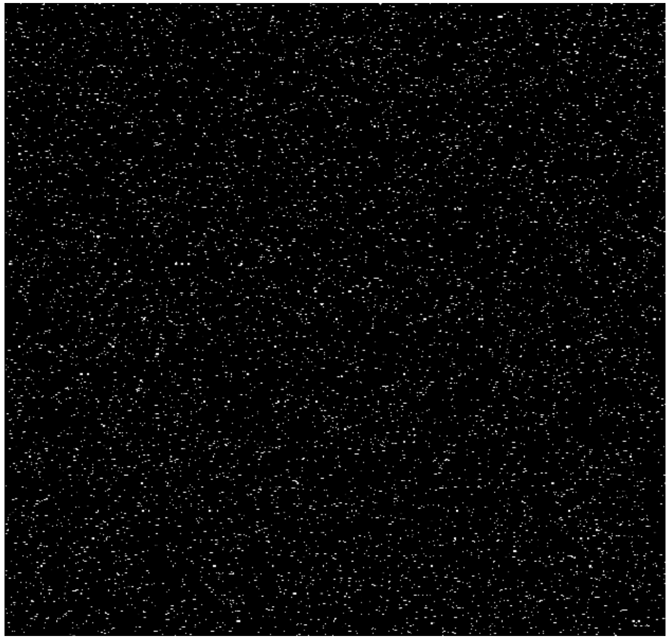


Image produced using mode 1

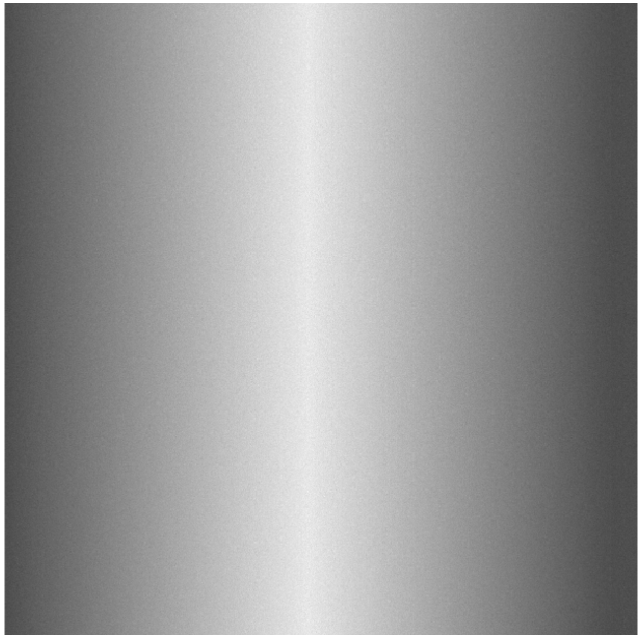
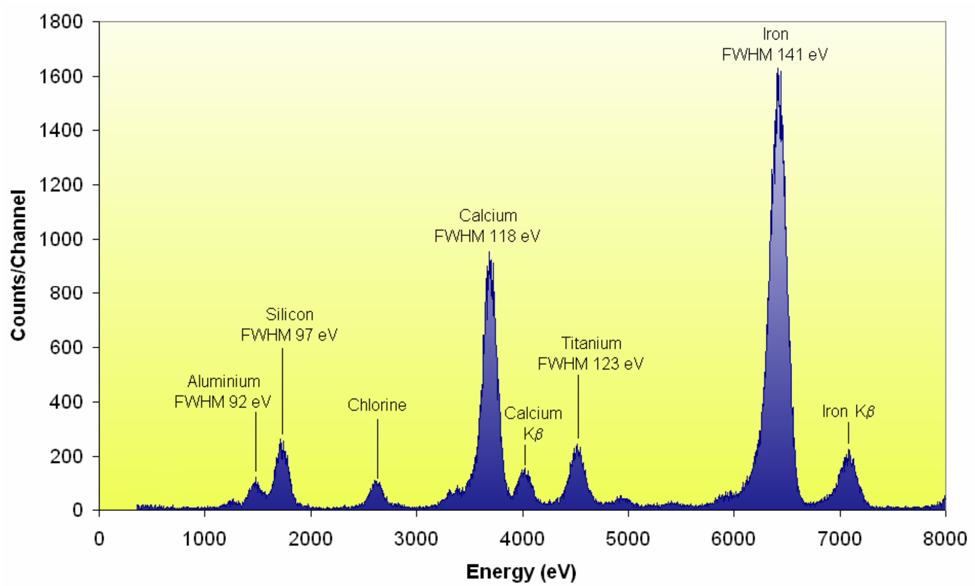


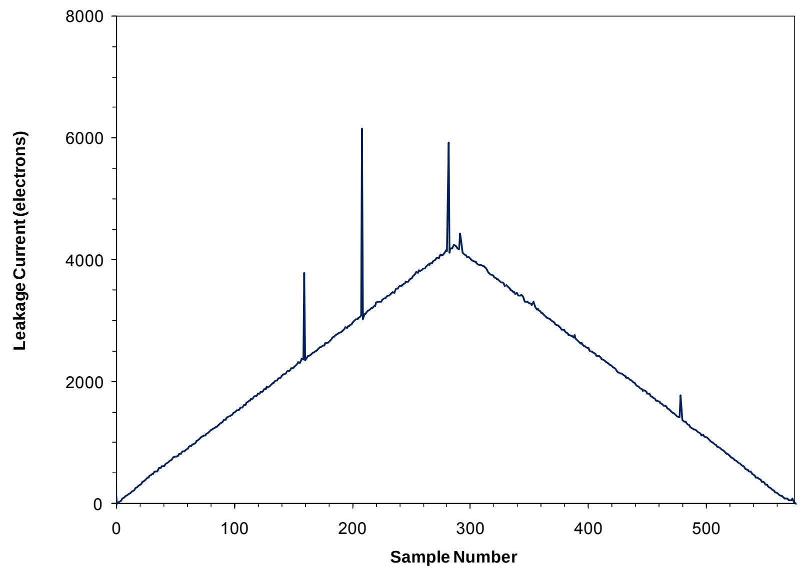
Image produced using mode 2

Operational Modes

- Mode 1
  - **resets the charge packets per sample**
  - produces an ‘image’ similar to that produced by a CCD
- Mode 2
  - **charge packets progressively sampled**
  - 10 ms delay between successive line readouts

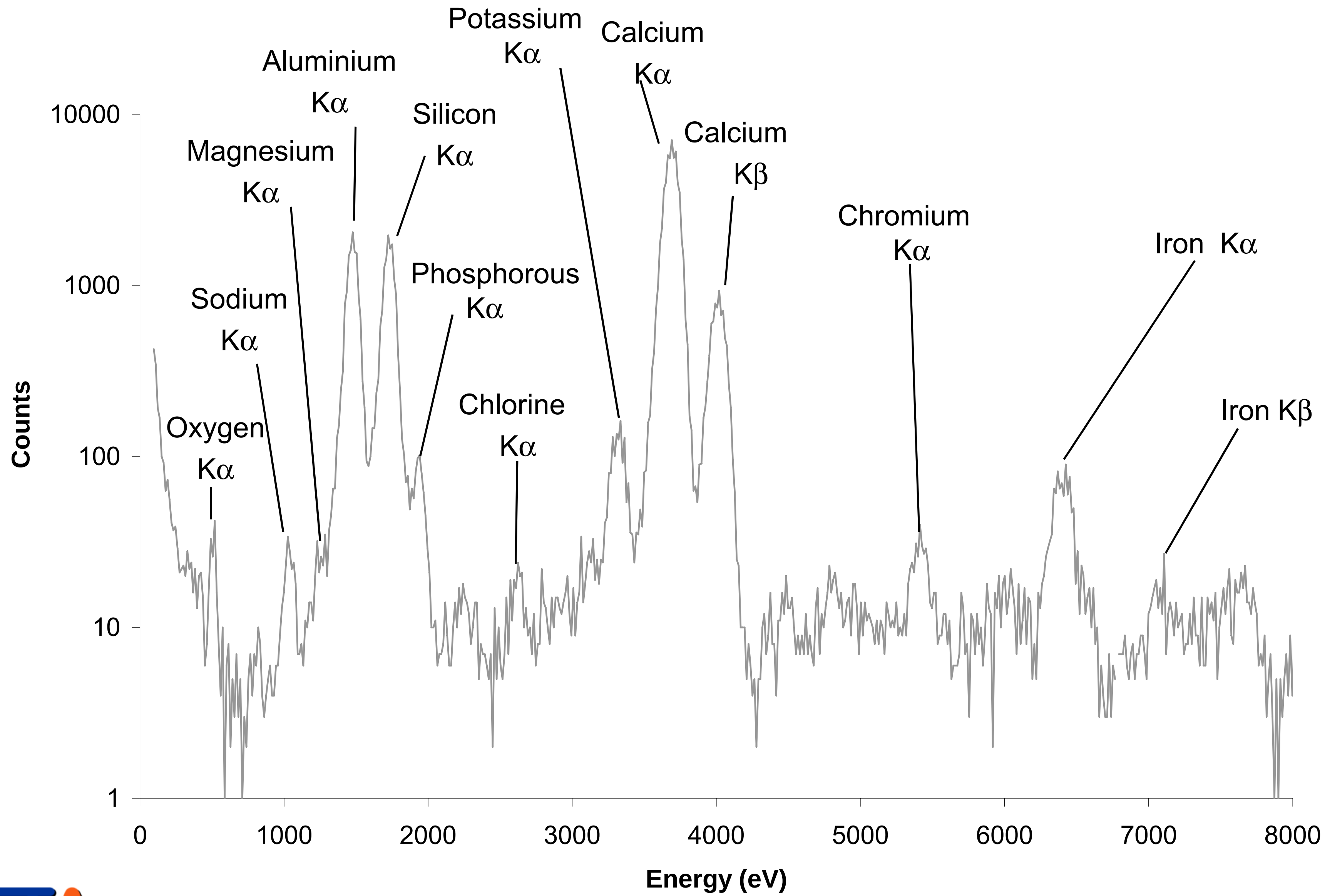


Basalt spectrum at -30^{o}C



Triangular leakage current profile for an SCD

Anorthosite, at -30ºC over 10 minutes



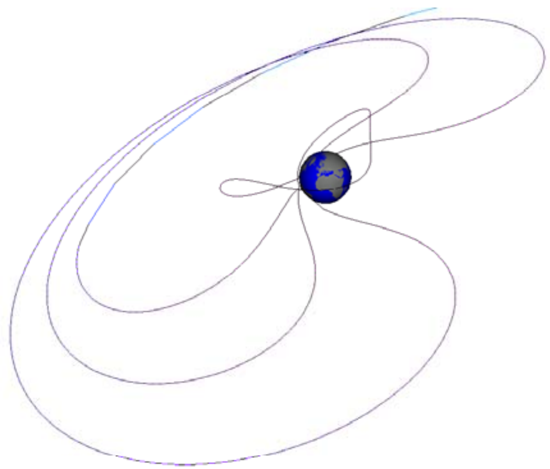
Going to the Moon

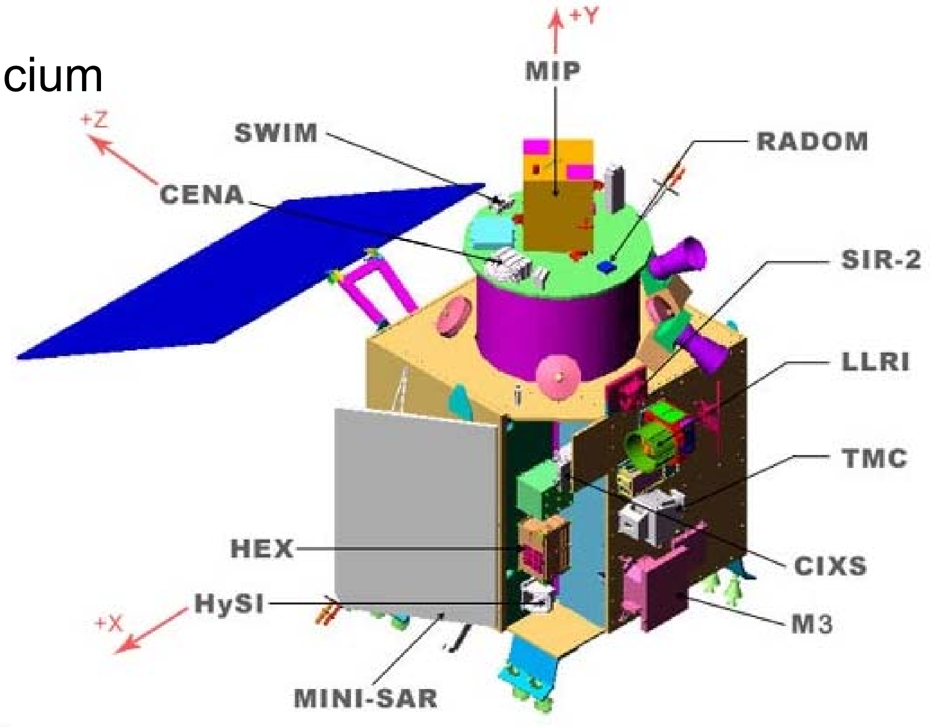
- During recent years there has been increased interest in the Moon
  - Chang'e 1 (China) Launched October 2007
  - SELENE (Japan) Launched September 2007
  - **Chandrayaan-1 (India)** September 2008
  - Lunar Reconnaissance Obiter (USA) November 2008

- Origins of the Moon
  - requires identification of elemental abundances of low Z elements such as Magnesium, Aluminium, Silicon, Calcium and Iron
  - the lunar surface provides information about the Earth's surface 4 billion years ago, comparable with the few rocks found from this time period
- Prospecting for suitable sites for a manned lunar base
- A good technology test bed for future missions to Mars and beyond

Chandrayaan-1 (Moonshot One)

- **Indian Space Research Organisation** (ISRO)
- To be launched using an Indian Polar Satellite Launch Vehicle (PSLV-XL)
- 2 year mission in a 100 km polar orbit
- Create a **3D atlas of the Moon**
- Conduct **chemical and mineralogical mapping** of the entire lunar surface for distribution of elements
  - Magnesium, Silicon, Aluminium, Calcium
  - Radon, Uranium, Thorium





Chandrayaan-1 X-ray Spectrometer (C1XS)

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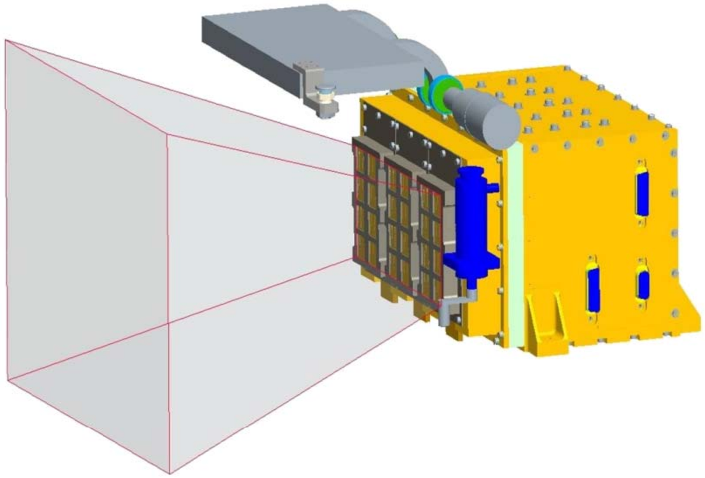

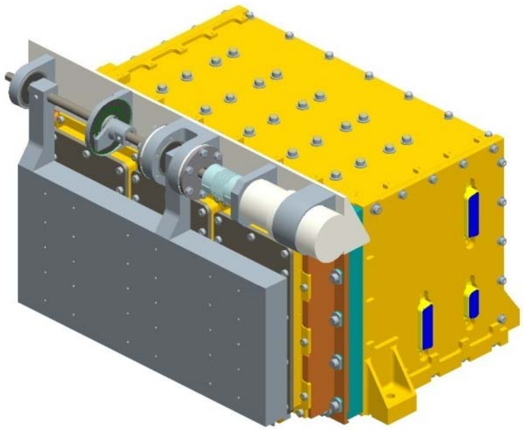

Detectors:

24 swept charge devices of 1 cm² each

E-range:	**1 – 10 keV**
E-resolution:	**180 eV @ 1.45 keV**
FOV:	**14°**
Ground Pixel:	**25 km × 25 km FWHM**
Mass:	**5.7 kg**
Power:	**35 – 42 V**

Calibration:

door mounted X-ray sources

Filters:

Al filters used to block sunlight

Elemental Range:

Mg, Al, Si, Ca (Ti, Fe)

Chandrayaan-1 X-ray Spectrometer (C1XS)

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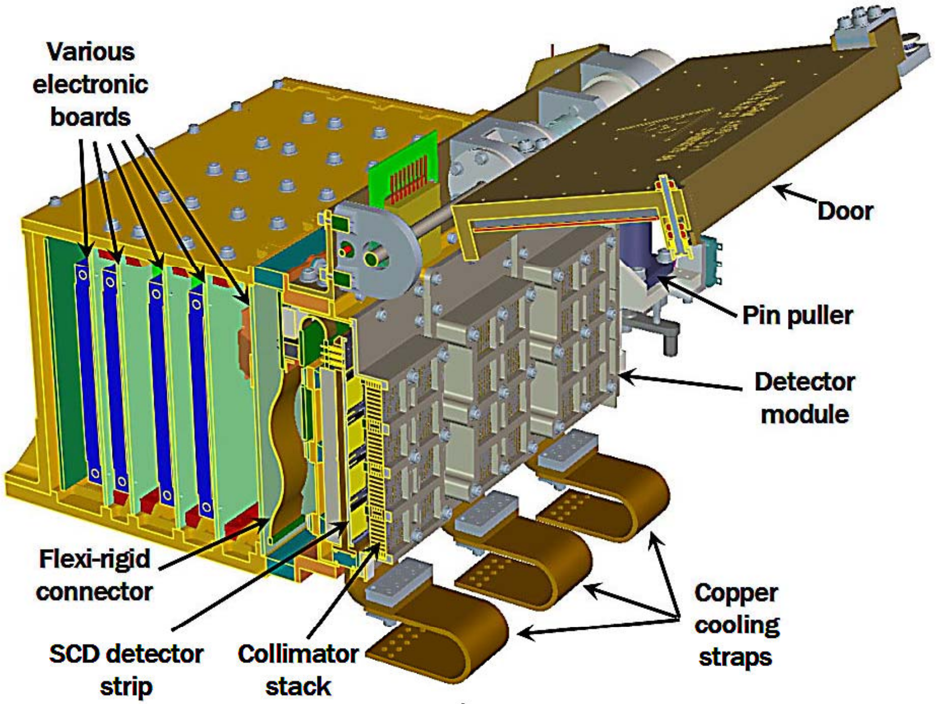
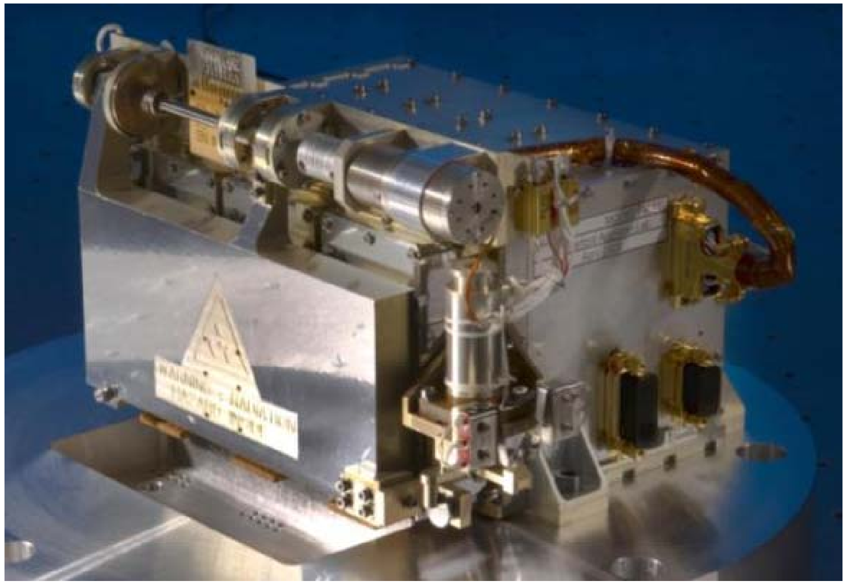
- Developed at STFC RAL and provided by ESA





Radiation Environment Modelling

- **Trapped and solar proton fluence spectra calculated for the 2 year mission duration using ESA SPace ENVironment Information System (SPENVIS) modelling software**

- **End-Of-Life (EOL) 10 MeV equivalent proton fluence calculated based on launch window, transfer time to the Moon and 2 year on-orbit operation**

- **Fluence then reduced by instrument shielding and proximity of the Moon:**
  - 3 mm Al + 6 mm Ta + spacecraft structure
  - 2π forward of the detectors is 100% shielded by the close proximity of the Moon

    (the gyration radius of a 100 keV proton is ~7500 km extending to much larger radii at higher proton energies)

Radiation Environment Modelling

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- **In early 2008 the calculated EOL fluence was recalculated**

- Updated SPENVIS calculations of fluence:
  - extra 1 mm of Al added to instrument surrounding structure (following output of the 2006 study)
  - change in launch date from April to October 2008 (Solar cycle starting up again, but relatively quiet...)

- Total revised EOL 10 MeV equivalent proton fluence is calculated to be:

7.5×10^{8} protons.cm^{-2}

Proton Irradiation

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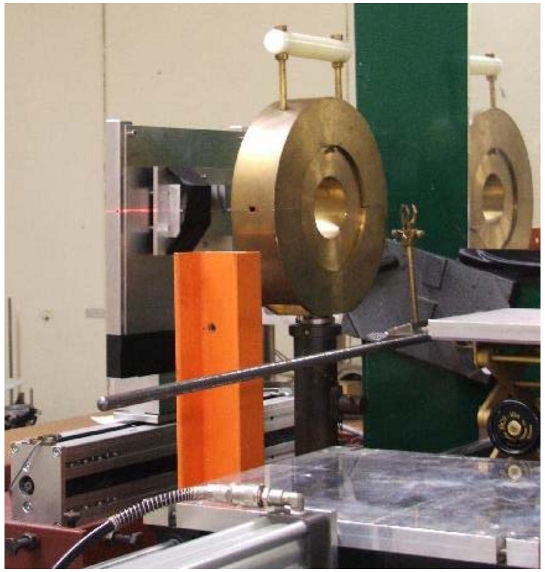
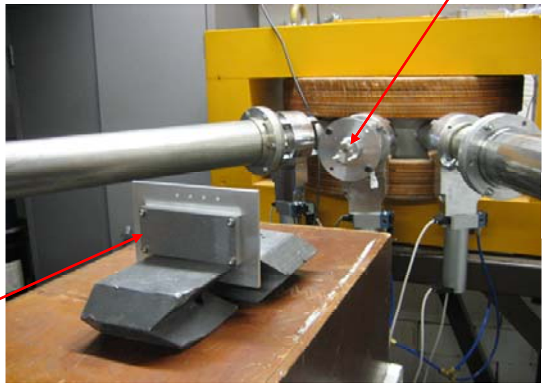
- **2006**
  - Irradiations carried out at Kernfysisch Versneller Instituut (KVI) in the Netherlands with beam time funded by ESA
  - 45 MeV proton beam facility
  - NIEL used to convert 10 MeV fluence requirement to 45 MeV



- **2008**
  - Irradiations carried out at University of Birmingham in the UK
  - 10 MeV proton beam facility

- All devices irradiated un-biased at room temperature



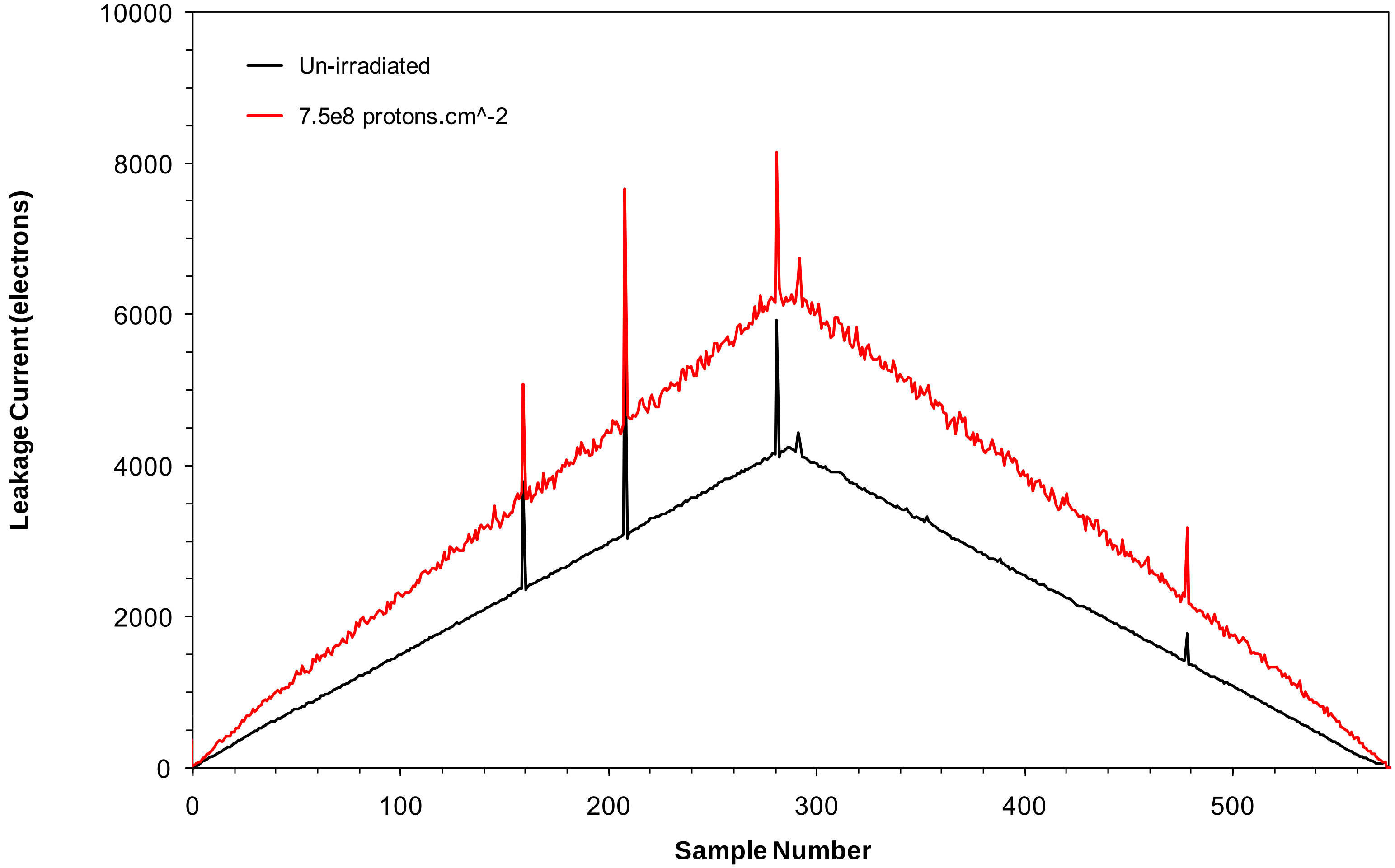
Proton Irradiation

- Summary of 10 MeV equivalent proton fluences investigated:

7.5×10^8 protons.cm^{-2}	(100% EOL)	2008 study
4.3×10^8 protons.cm^{-2}	(57% EOL)	2006 study
3.0×10^8 protons.cm^{-2}	(40% EOL)	2008 study
2.1×10^8 protons.cm^{-2}	(28% EOL)	2006 study

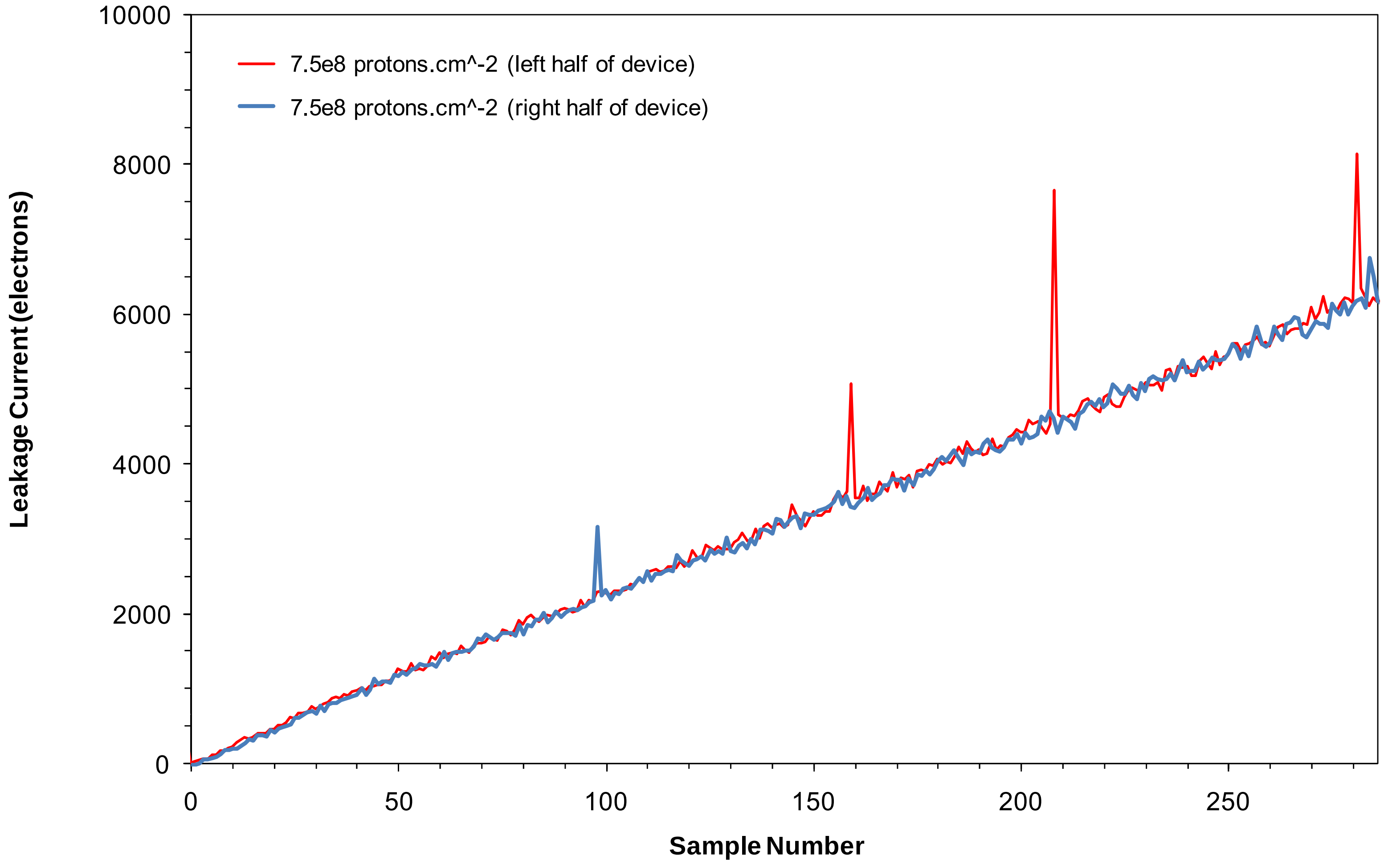
Leakage Current Profile

- Increase in triangular leakage current profile at -20^{o}C



Leakage Current Profile

- Leakage profiles used to confirm beam uniformity



FWHM at Mn-Kα (5898 eV)

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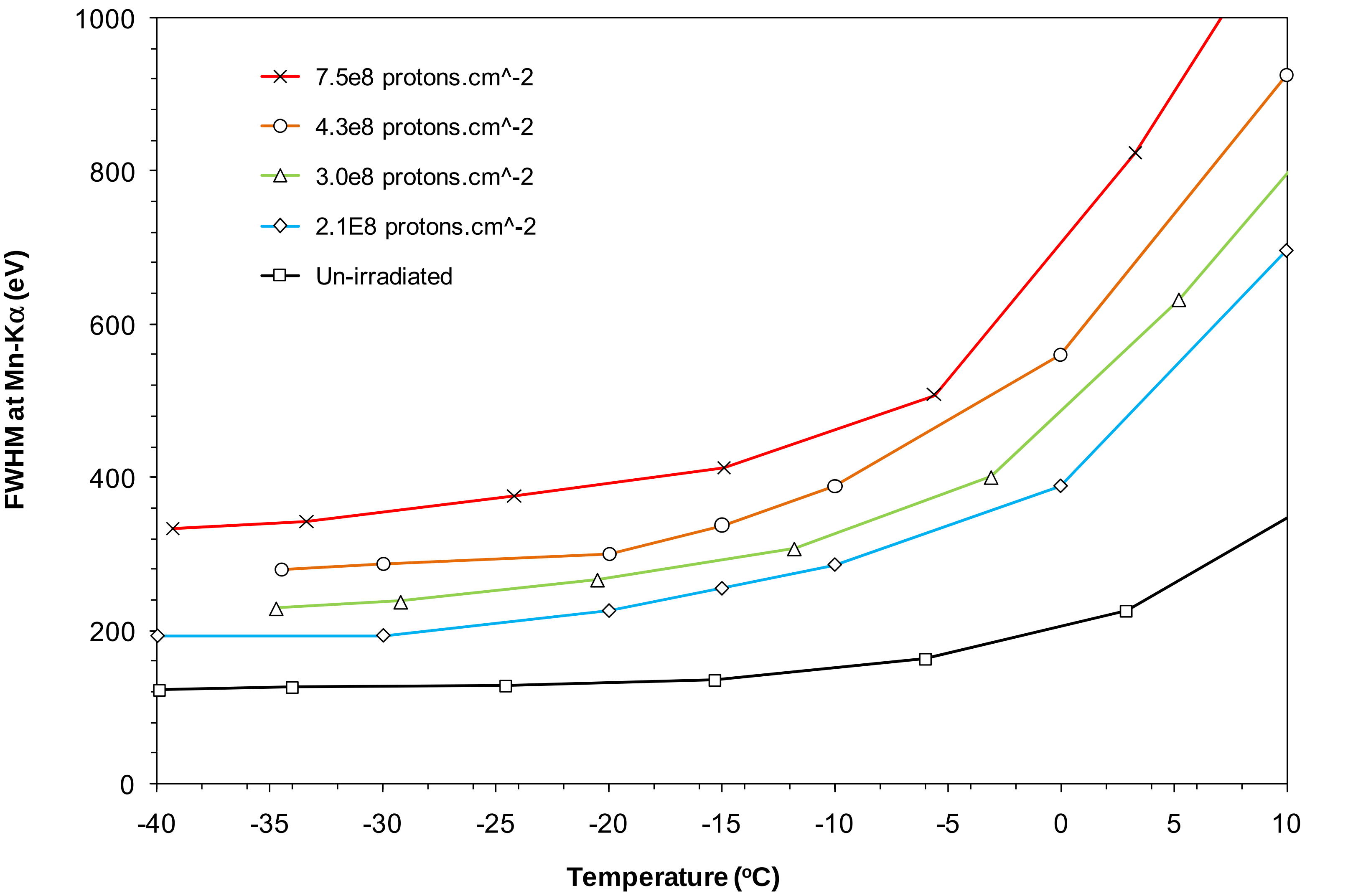
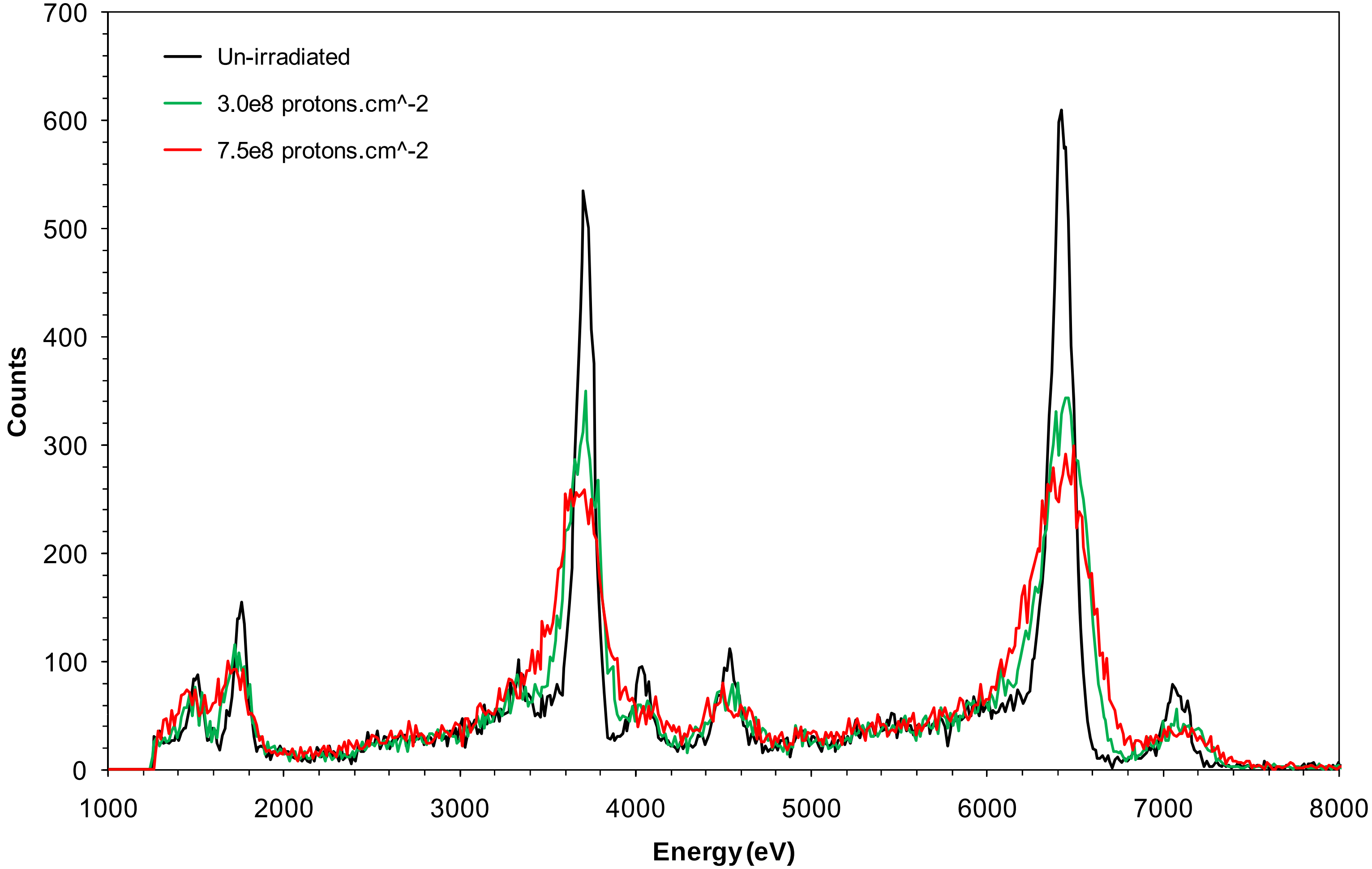


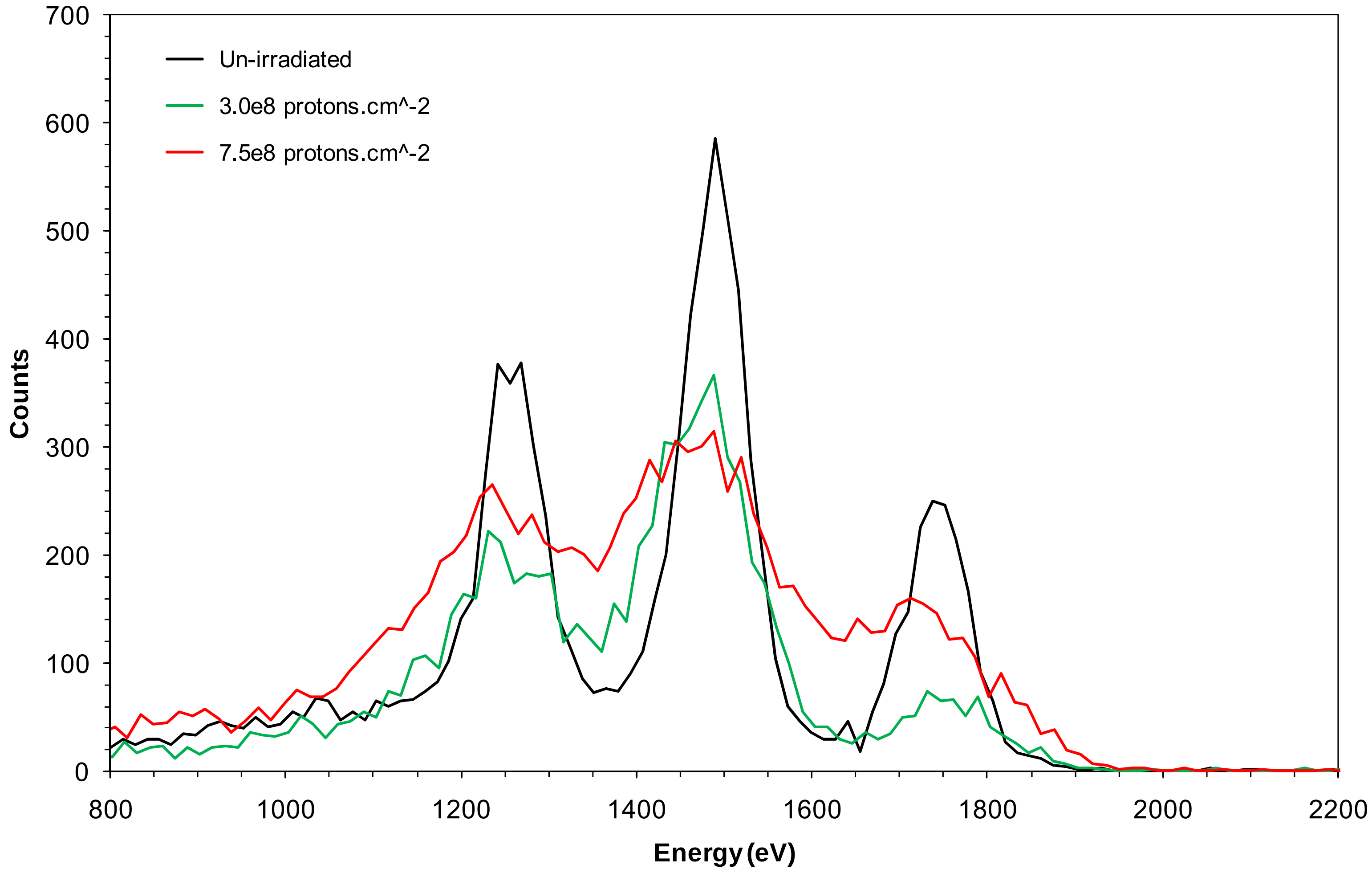
Lunar Regolith Simulant (JSC-1A)

- Spectra at near mission operating temperature of -20^{o}C



X-ray spectra from Mg, Al and Si

- Spectra at near mission operating temperature of -20°C



Summary of FWHM Results

10 MeV equivalent fluence (protons.cm^{-2})	*Elapsed mission time (%)*	*FWHM (eV) Aluminium*	*FWHM (eV) Calcium*	*FWHM (eV) Manganese*	*FWHM (eV) Copper*
0	0	95	122	134	153
2.1×10^8	28			226	
3.0×10^8	40	142	200	268	286
4.3×10^8	57			300	
7.5×10^8	100	238	350	390	420

Study Conclusions

- After proton irradiation up to a fluence of 7.5×10^8 protons.cm^{-2} all SCDs tested were found to remain fully functional
- Leakage current increases proportional to proton dose, increasing by up to 60% after irradiation to 7.5×10^8 protons.cm^{-2}
- Resolution of 250 eV FWHM at Mn-Kα is achievable up to a fluence of 3.0×10^8 protons.cm^{-2} when operating at -20^{o}C
- For space use, essential to avoid excessive time within the Earth's radiation belts
  - 2.9×10^6 protons.cm^{-2}.day^{-1} from trapped protons
  - 0.1×10^6 protons.cm^{-2}.day^{-1} from solar protons
- Increased CTI as a result of displacement damage is the dominant component in loss in detector performance

- Calculated EOL proton fluence for C1XS is **worst case**
- C1XS should perform well over the 2 year mission!

Acknowledgements

- Chris Howe, STFC Rutherford Appleton Laboratory
  - for provision of the SCD modules used in the irradiation studies
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