HIGH-ENERGY X-RAY SPECTROMETER (HEX) ON CHANDRAYAAN-1: STUDIES OF VOLATILE TRANSPORT ON MOON AND MAPPING OF U, Th-RICH TERRAIN. P. Sreekumar.[1], C.N. Umapathy[1], M. Ramakrishna Sharma[1], C.V. Sreekantha[1], A. Tyagi[1], Kumar[1], M. Sudhakar[1], L. Abraham[1], R. Kulkani[1], R.L. Premlatha[1], A.K. Srivastava[1], S. Neeraj Kumar[1], M. Bug[1], Y. B. Acharya[2], S. Vadawale[2], M. Shanmugam[2], D. Banerjee[2], S. Purohit[2], H. Patel[2], J. N. Goswami[2], [1] ISRO Satellite Centre, Bangalore 560017, India. [2] Physical Research Laboratory, Ahmedabad 380009, India. (e-mail: pskumar@isac.gov.in)

Introduction: In-situ measurements, remote sensing technique and laboratory analysis of returned samples provide information on the elemental composition of a planetary body. High energy (>500 keV) gamma ray spectroscopy is a prime tool for remote sensing studies of chemical composition of planetary surfaces. So far detection of lower energy (<500 keV) gamma rays has not been attempted because of low signal strength and the anticipated high detector and planetary continuum background. With the development of new solid state array detectors it is now possible to explore this energy region. The High Energy X-ray (HEX) experiment on board Chandrayaan-1 is designed primarily to study the emission of low energy (30-270 keV) natural γ-rays from the lunar surface due to radioactive decay of ^{238}U and ^{232}Th, and in particular, address the question of volatile transport on lunar surface towards lunar polar regions using radon as a tracer.

Volatile Transport on Moon: The extreme nature of thermal baking and cooling of the lunar surface leads to pole-ward transport of lunar volatiles implying their higher concentrations in permanently shadowed regions near the pole [1]. In fact, the possibility that there could be substantial reservoir of water ice embedded in lunar soil in such polar regions of the moon is based on this concept. HEX is designed to investigate the transport of volatiles on the lunar surface through the detection of the 46.5 keV γ-ray line from radioactive ^{210}Pb (half-life ~22 years), a decay product of the volatile ^{222}Rn (half-life ~4 days), both belonging to the ^{238}U series. Transport of ^{222}Rn to cold polar traps could manifest in a significant enhancement in the emission of the 46.5 keV gamma ray in these traps relative to the rest of the Moon. Other prominent emission lines from ^{234}Th (63.3, 92.4 and 92.8 keV), ^{226}Ra, ^{235}U (186.2 and 185.7 keV) and ^{212,214}Pb (238.6 and 214.9 keV) will also be studied to obtain low spatial resolution U and Th map of the polar and U-Th enriched (e.g. KREEP) regions. The possibility of inferring compositional characteristics of various lunar terrains, based on the shape of the continuum below 100 keV [2] will also be attempted.

Both line and continuum emission are expected in the 30-270 keV energy range in the lunar environment. We estimated expected fluxes for a field of view covering 33 km × 33 km of the lunar surface from a 100 km lunar orbit. Model calculations suggest the lunar continuum background in the energy range of interest (30 -270 keV) to be ~ 0.001 to 0.0025 counts s^{-1} cm^{-2} keV^{-1}, while the detector (CZT) background at this energy range and specific to space environment could be ~ 0.0006 s^{-1} cm^{-2} keV^{-1}, when active anticoincidence shield is employed [2, 3]. For emission from U, Th enriched (KREEP) regions of the Moon, conservative estimates show required exposure times ranging from 10 minutes (^{212}Pb, 238.6 keV) to 14 hours (^{228}Ac, 209.2 keV) for detection of signals at 3 sigma level above background. Nominal exposure time required for the 46.5 keV line from ^{210}Pb will be several hours. However, if volatile transport to colder polar trap is operating on the moon, the signal of the ^{210}Pb line in the polar region is expected to be significantly enhanced and the total exposure time requirement for detection will be correspondingly reduced. The polar orbiting Chandrayaan-1 will facilitate accumulation of signal over the polar region for long durations and it should be possible to detect expected enhanced signal of the ^{210}Pb line and quantify the magnitude of volatile transport on the lunar surface.

The HEX Payload: A preliminary description of the HEX payload was reported previously [3]. It consists of nine (3×3) Cadmium-Zinc-Telluride (CZT) detector arrays, each detector is of area 4 cm×4 cm and 0.2 cm thick and composed of 256 (16×16) pixels (2.4mm×2.4mm) providing a geometric area of 144 cm^2. A CsI(Tl) scintillator crystal coupled to photomultiplier tubes, is used as the anticoincidence detector system (ACS). The ACS identifies scattered events on the basis of a 3 μsec coincidence window for signals from CZT and ACS. Coincident events are tagged and can be screened out during ground processing. Any one of the four independent ACS energy channels can be selected by command for event tagging. Appropriate collimation is provided to have an effective field of view of 33 km × 33 km (FWHM) at energies below 120 keV. The associated electronics collects the pixel ID, energy, time and formats the data and store into the onboard solid state recorder which is transmitted to ground along with relevant housekeeping data.

The detector system and the control electronics are two physically separate units which when connected together forms the full HEX payload hardware. HEX payload has been subjected to thermal cycling in

Table 1: HEX specifications

Parameter	FM specifications
Energy range	30 – 270 keV
Energy resolution	12 % at 60 keV
ACS threshold	~ 50 keV
Spatial resolution	33 km × 33 km FOV

a vacuum chamber (thermovac) and vibration tests simulating launch conditions. Mechanical integrity and consistency in electrical performance were checked before and after vibration. Subsequently, the payload was placed inside a thermovacuum chamber where the electrical performance of the system was tested at a few microtorr for extremes of temperatures (-20 deg C to +50 deg C) expected in lunar orbit. All HEX performances were monitored and nominal performances were observed. The operating temperatures for the CZT detectors on HEX are designed to be below +10 degrees C. Due to the large sensitive area of CZT (144 cm^2), active cooling of these detectors was not considered and instead a passive cooling configuration is implemented using a heatpipe and radiator.

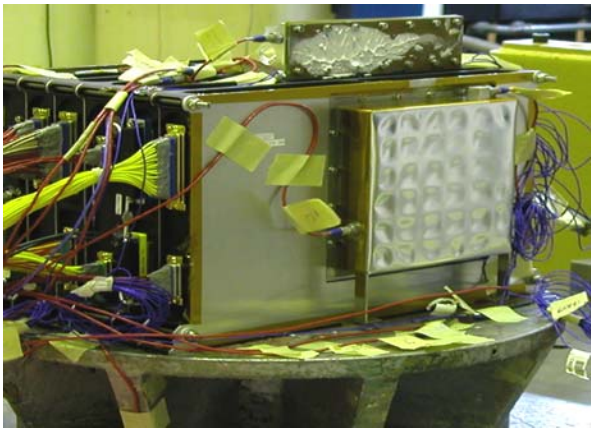

Fig.1. HEX undergoing vibration test

Ground calibration efforts focused on deriving the conversion of ADC channels to photon energies for each of the 2304 pixels of CZT. The setup consisted of positing of known radioactive sources, Co-57 (122 keV) and Am-241 (59.6 keV) and Ba-133 (30, 80 & 256 keV) in front of the HEX collimator, which cover the 30-270 keV energy range of HEX. The primary CZT calibration tests involved generation of spectra from these sources across all pixels and at various temperatures to derive the energy resolution, gain and offset determination (to convert ADC channels to energy units), all as a function of a few discrete temperatures. This database is then used to derive values of the above pixel parameters for any energy and detector temperature.

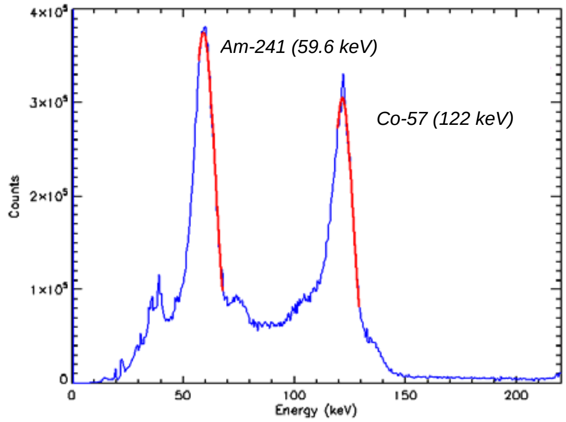

Fig. 2. Summed spectrum from all pixels after applying pixel gain and offset corrections (ground test results).

HEX commissioning: The HEX payload onboard Chandrayaan-1 was commissioned in December 2008. Initial results obtained show nominal functioning of all sub-systems. Pre-launch thermal model had indicated that during conditions when the Sun-Moon-Spacecraft angle is smaller than 25^0C, the thermal requirement of HEX detector may not be met throughout the orbit. Monitoring of HEX data in orbit during the commissioning phase, when the solar phase angle was indeed close to zero, showed nominal detector temperatures during half the orbit. When detector temperature increases, noisy pixels are anticipated as seen from ground tests and hence HEX has not been operated for long periods during this unfavourable time frame in December 2008 because of thermal consideratios. Normal HEX operations are planned towards the end of January when the solar pahse angle increases beyond 25^0C. Nevertheless, as the HEX payload will be continuosly operating during all thermally favourable times, there will be adequate coverage of the polar regions to address the issue of volatile transport on moon and also sufficient lunar surface coverage during the two year nominal mission to address the other science objectives of the HEX experiment.

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