New low electron flux facility in the 0 to 3.5 MeV range for the study of induced signal in JUICE instruments: UVS and MAJIS measurements

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***Abstract*—We designed and built a new test facility to investigate signal induced by electrons in the 0-3.5 MeV in the JUICE UVS and MAJIS instruments. The facility uses radioisotopes sources to produce low flux of electrons (< 6000 electrons/cm².s). We present the facility, its capabilities and the results of measurements on UVS and MAJIS.**

***Index Terms*—Jupiter, electrons, radiation induced signal, test facilities**

1. INTRODUCTION

THE first large-class mission in ESA's Cosmic Vision 2015-2025 is a planetary probe called JUICE (JUpiter ICy moons Explorer) [1] that will study the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa. Jupiter's radiation environment is very harsh [2] and the radiation shielding of the spacecraft is critical; even with optimized shielding [3], onboard instruments will be submitted to high level of radiation. Therefore it is mandatory that these instruments are tested for Total Ionization Dose (TID) [4] and Single Event Effect (SEE) [5] tests. Even with proper SEE mitigation, radiation will induce nondestructive signal in the instruments. A major concern is the electron induced signal resulting from of the high level of electron radiation in Jupiter radiation belt compared to the levels observed for earth orbits (LEO or GEO).

We designed and built a new test facility to study the electron induced signals in JUICE MAJIS [6] (Moons And Jupiter Imaging Spectrometer) and UVS [7] (UltraViolet Spectrograph) instruments. The flux of electrons has to be very low to achieve individual measurement of induced signal; maximum flux requirement is around 6000 electrons/cm².s. Such low flux is not easily achievable with particle accelerator because it would require beam current regulation in the 1E-16 Ampere range. Therefore we decide to use pure β^- radioisotopes sources as electrons source.

2. FACILITY DESCRIPTION

The facility consists of a vacuum chamber and its associated equipment (primary and turbomolecular pump, RGA, pressure sensors, temperatures sensors and datalogger), four pure β^- radioisotope sources, mechanical displacements, liquid nitrogen supply and high resolution electron spectrometer.

2.1. Electrons sources

The electron beam is provided by four different electron sources with an energy range from 0 to 3.5 MeV; the available sources are:

$^{147}_{61}\mathrm{Pm} \rightarrow {}^{147}_{62}\mathrm{Sm} + \beta^-$ with E_{β^-} maximum of 0.224 MeV

$^{36}_{17}\mathrm{Cl} \rightarrow {}^{36}_{18}\mathrm{Ar} + \beta^-$ with E_{β^-} maximum of 0.796 MeV

$^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + \beta^- \rightarrow {}^{90}_{40}\mathrm{Zr} + \beta^-$ with E_{β^-} maximum of 0.546 and 0.643 MeV

$^{106}_{45}\mathrm{Rh} \rightarrow {}^{106}_{46}\mathrm{Pd} + \beta^-$ with E_{β^-} maximum of 3.564 MeV

^{147}Pm source has an activity of 3.7 kBq and a half-life of 2.6234 years, ^{36}Cl source has an activity of 37 kBq and a half-life of 3.02E5 years, ^{90}Sr/^{90}Y source has an activity of 3.7 kBq and a

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half-life of 28.5 years and ^{106}Rh source has an activity of 37 kBq and a half-life of 1.02 years. Due to their short half-life ^{106}Rh and ^{147}Pm sources are considered as consumable and can be replaced before each test campaign if flux requirements are not met due to their natural decay.

Radioisotope sources are at atmospheric pressure and the electrons reach the inside of the vacuum chamber through an opaque, vacuum tight, electron transparent windows. The windows consist in a 145 nm thick SiN layer between two Al layers of 120 nm each. A 15 µm thick hexagonal silicon support grid is attached to the window underneath. A Geant4 (version 4.9.6) simulation of electron transmission through the window shows that 99% of the electrons are transmitted by the window losing less than 0.3-3% (depending on incident energy) of their energy.

The chamber contains a liquid nitrogen cooled high resolution electron spectrometer (Canberra Silicon Lithium ESLB 200-5000 model with resolution of 1.7 keV at 624 keV); the energy calibration of the whole spectrometer setup (detector, charge conversion, pre-amplifier and shaping amplifier) is done using the conversion electrons from a ^{137}Cs source. The spectrometer is used to record the energy spectrum of the four β^- radioisotope sources. The measured spectra are given in Fig. 1.

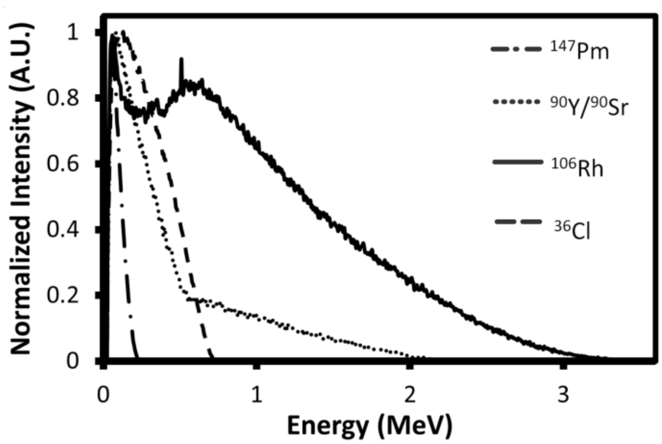

Fig. 1. Measured energy spectra of the electrons from the four radioisotopes sources.

2.2. Mechanical design

The vacuum chamber has a diameter of 850 mm and a length of 764 mm, the whole setup is mounted on wheel and can be moved to class 10000 or class 100 clean room (ISO 14644). The general setup is illustrated in Fig. 2.

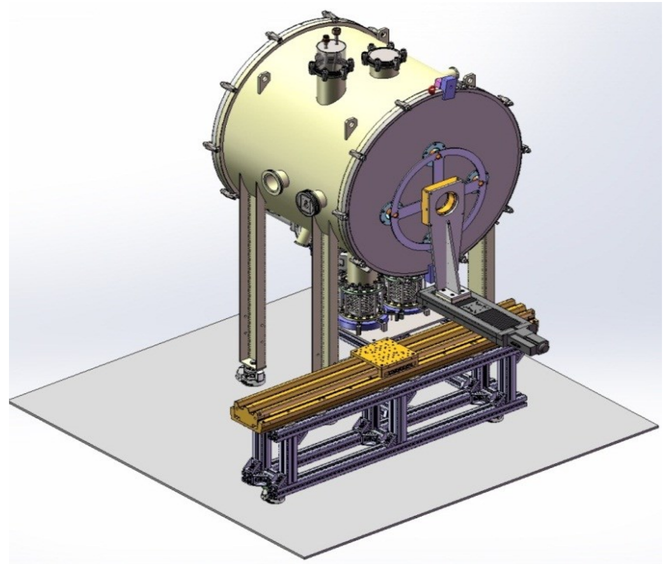

Fig. 2. General setup.

Initial position of the sources and the device under test (DUT) are measured with a laser tracker (Radian API) with an accuracy of 10 microns.

Source positioning is done using three motors. The first motor is used to place the source in front of the DUT in the horizontal axis (perpendicular to the DUT-source axis). We use a Newport M-IMS1000LM with a bi-directional repeatability of ± 0.5 µm. This motor has a range of 1 meter and also allows source positioning next to the chamber to do measurement on device at atmospheric pressure or included in a custom setup (i.e. MAJIS cryostat).

The second motor used is a rotation stage for the source selection. We use a Newport URS150BPP with an angular bi-directional repeatability of ± 0.01°

The last motor is used to move the source close to the DUT along the axis joining the center of the DUT and the center of the source. This motor can be used to reduce the flux reaching the detector by increasing the source-DUT distance. The motor used is a Newport MTN300PP with a bi-directional repeatability of ± 2.75 µm. All the sources have the same geometry and a diameter of 3 mm (ECKERT & ZIEGLER NUCLITEC GmbH MF2 model source holder) therefore they may not be considered point sources and could not follow the $1/r^2$ flux variation with distance r for a punctual source. Nevertheless, real measurements of flux variation with distance follows quite well the $1/r^2$ law. The Fig. 3 gives the measured flux for distance from 9 to 95 mm.

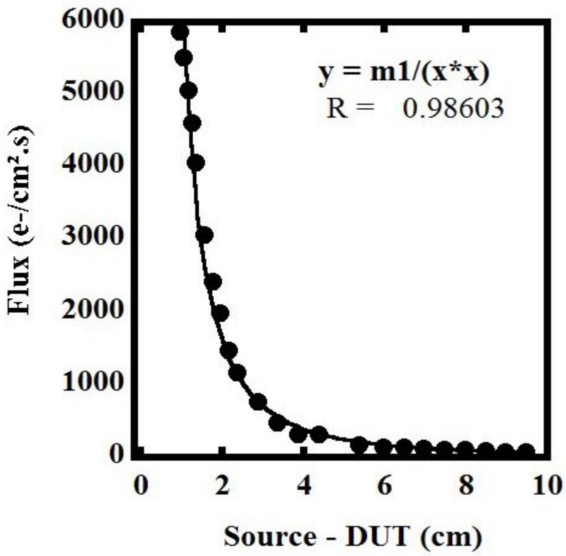

Fig. 3. Flux variation with source-DUT distance.

This flux is measured using the spectrometer and the 37 kBq ^{36}Cl source in the 0.04-1.16 MeV energy range for electrons to ensure no fluorescence photons are counted (the spectrometer is also sensitive to photons). Fig. 3 shows that we can provide a flux from 0 to 6000 electrons/s.cm² when the source has its maximum activity (37 kBq).

3. Measurements results

The facility is used for JUICE MAJIS and UVS instruments.

3.1. MAJIS measurements

The MAJIS instrument from CNES and IAS fulfills and further expand the scientific objectives of VIRHIS (Visible and Infrared Hyperspectral Imaging Spectrometer), one of the core-payload instrument of JUICE. MAJIS is suitable to perform imaging spectroscopy in the spectral range from 0.4 to 5.7 µm, including the investigation of the nature and location of chemical compounds (especially organic and non-ice constituents) on the surfaces of the Galilean satellites, the characterization of their exospheres, the monitoring of peculiar aspects (Io and Europa tori, Io's volcanic activity), the study of Jupiter's atmosphere at different levels (including aurorae and magnetic footprints), and the spectral characterization of the whole Jupiter system (including ring system, small inner moons, and targets of opportunity).

MAJIS onboard JUICE will receive incoming fluxes of high energy electrons that will generate signal spikes. If 5% of the pixels present spikes, reversible compression requires data volume to be multiplied by two. If data volume is fixed to nominal value, then data distortion is increased by a factor of 10 with 5% of spikes. Severe radiation conditions at Europa are expected to produce up to 18 electrons / pixel / integration. If most electrons produce spikes, then a strong despiking strategy is required for MAJIS. The target residual spike occurrence is ≤ 1%. The considered onboard automatic despiking algorithm relies on a time filtering approach (a given observation is divided in sub-integrations that should produce identical signals: if a spike occurs on a given sub-integration, it is identified and the sub-integration with spike is removed from the mean), which is relevant if electrons produce spikes that do not persist with time.

Results of the test campaign show that most electrons produce spikes in the tested energy range, with some electrons even producing spikes over several adjacent pixels (Fig. 4).

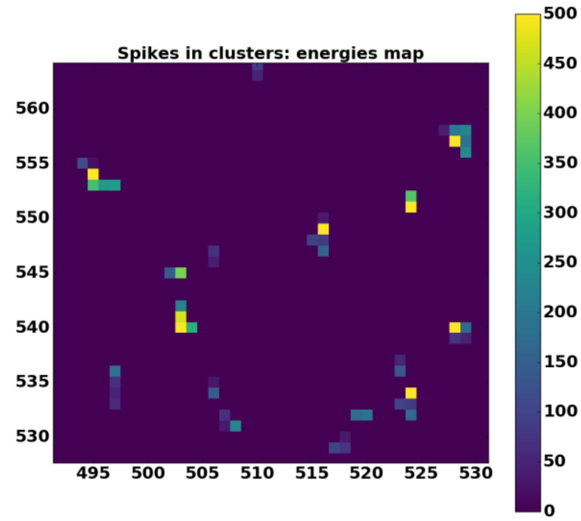

Fig. 4. Example of spikes clustering observed in a subsection of the detector for ^{36}Cl source with T = 90 K, and integration time of 1s.

This implies that electron fluxes give a correct estimate of the spikes fluxes that need to be filtered by the algorithm. Results also show that electrons do not generate persistent spikes over successive frames, which was required for the time filtering approach to be efficient (integration time is divided in sub-intervals: a spike must occur in one sub-interval only to be removed). Fig. 5 gives an example of spike with a high intensity of ~650 DN with DN being quantization step defined by the gain of the ADC for converting the signal (number of collected electrons) into a numerical output. The spike measured during observation # 24 has no significant impact on the following observation #25. The results illustrated in Fig. 5 are obtained with the ^{106}Rh source, MAJIS detector temperature was ~90K and the integration time is 100ms.

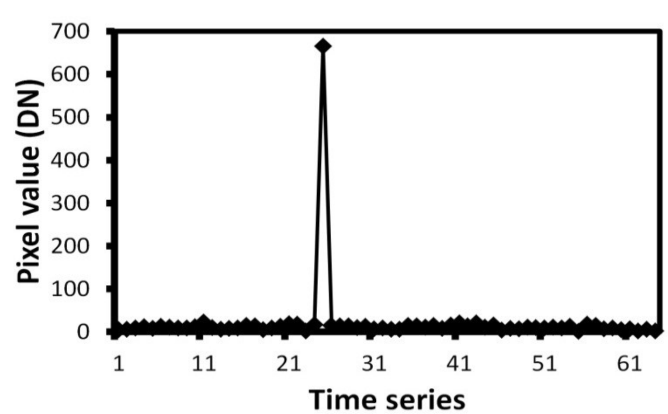

Fig. 5. Example of spike with a high intensity.

All MAJIS measurements are done with an additional liquid nitrogen cooled plate in front of the detector, without this plate the IR detector would saturate at ambient temperature. As the electrons from the source go through this plate they lose energy before reaching MAJIS detector. As this cooled plate has a complicated geometry and composition, direct measurement (instead of GEANT4 simulation) of energy spectrum is done by placing the plate in front of the electron spectrometer to obtain the exact energy spectrum of the electron reaching the detector as given in Fig. 6.

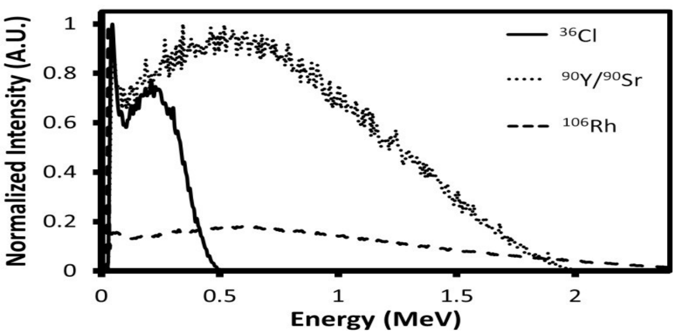

Fig. 6. Measured energy spectra of the electrons behind the cold plate used in MAJIS setup, electrons from ^{147}Pm source are completely absorbed in the plate.

3.2. UVS measurements

The UVS instrument from NASA and SwRI is a long-slit ultraviolet imaging spectrograph, with a spectral band pass including extreme and far-ultraviolet wavelengths in the 55–210 nm range. It will be used to explore the atmospheres, plasma interactions, and surfaces of the Galilean satellites, determine the dynamics, chemistry, and vertical structure of Jupiter's upper atmosphere, from equator to pole, as a template for giant planets everywhere; and investigate the Jupiter-Io connection by quantifying energy and mass flow in the Io atmosphere, neutral clouds, and torus. UVS will obtain excellent airglow and auroral observations, stellar and solar occultations, and surface albedo maps to address JUICE science goals even in the worst-case radiation environment near Europa. The purpose of this test is to measure the Quantum Efficiency (QE) of the Microchannel Plate Detector (MCP). Previous tests with the Juno-UVS spare detector indicate a 30 % QE with respect to 1 MeV electrons [8]. The QE is expected to increase as electron energy decreases [9]. A first estimation of the QE (flux normalized by the activity of the source) as a function of peak energy is plotted in Fig. 7. For three of the four sources, the QE trend follows our intuition that QE is inversely proportional to electron energy. The lowest energy source appears to disagree with this trend. The QE also seems to be higher than previously measured with monoenergetic electron beam from particle accelerator [7]. Further analyses are necessary to understand these discrepancies, they will take into account other parameters: High Voltage (HV) applied on the MCP, energy spread of each source, secondary particles induced in the photocathode… . New measurements should be done to investigate experimental parameters: flux variation by increasing the source-detector distance and different MCP HV values.

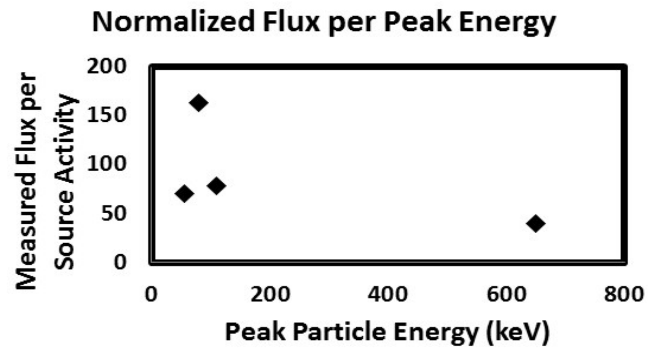

Fig. 7. Detector efficiency as a function of peak energy.

4. Conclusion

The facility fulfills the requirements of very low flux of electrons for the study of individual electron induced signal. These requirements cannot be met using particle accelerator. The results obtained on MAJIS and UVS will help to improve the compression algorithm (MAJIS) and take into account the influence of electron on micro channel plate (UVS)

Acknowledgements

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