X-RAY FLUORESCENCE EXPERIMENTS ON THE SELENE(KAGUYA) SPACECRAFT. T. Okada[1], K. Shirai[1], Y. Yamamoto[1], T. Arai[1], K. Ogawa[1,2], H. Shiraishi[1], M. Iwasaki[1,2], T. Kawamura[1,3], H. Morito[1,3], M, Kato[1-3], and the SELENE XRS Team, [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan. (okada@planeta.sci.isas.jaxa.jp), [2]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, [3]Department of Earth and Planetary Science, University of Tokyo.

Introduction: The Japanese lunar polar orbiter SELENE (SELenological and ENgineering Explorer) is now in the circular orbit around the Moon at the altitude of 100km. SELENE is named as “Kaguya”, a lunar princess in the Japanese fairy tale. SELENE has 15 missions including X-ray fluorescence (XRF) spectrometry to map major elemental composition of the entire surface of the Moon.

As was proven during the Apollo 15 and 16 missions, major elemental composition can be determined through remote XRF method for atmosphere-free planetary surfaces. Solar X-rays irradiate planetary surface to excite X-ray fluorescence at the uppermost layer of surface materials, which is characteristic of major elements. Intensities and spectral profiles of solar X-rays varies time to time, which affects those of XRF off the planetary surfaces as well. Therefore mapping of major elemental composition from the orbit requires concurrent monitoring of solar X-rays.

One of the key objectives of the SELENE mission is to map the surface mineralogical and elemental composition using Visible-to-Near-Infrared spectroscopy, X-ray and gamma-ray spectroscopy. XRF spectrometry aims at mapping most major elemental composition, especially in Mg, Al, and Si with complete coverage except at polar region, and in Ca, Ti, and Fe at the scale of basin (detection of there elements are expected only during solar flares). To achieve those purposes, the XRS instrument consists of CCD-based main detector with a direct monitor of solar X-rays as well as XRF calibrator aboard. We present here the scientific objectives, instrumentation of the XRS, as well as its current status around the lunar orbit.

Scientific Objectives: Scientific objectives of the XRS observation are (1) global mapping of major elements of lunar surface materials except for polar regions during day time observation, (2) understanding the physical processes of lunar X-ray illumination in the night time that happens by impact of solar wind particles and comic rays as well as natural radioactivity, and (3) regional variation of surface microscopic roughness as a result of particle size effect on XRF.

Lunar XRF experiments have mapped about 10 % of the lunar equatorial regions during the Apollo 15 and 16 missions in 1971-1972 and implied that lunar maria are covered with lava flows in basaltic composition and lunar highlands are dominantly occupied with aluminous anorthosetic materials [1]. Tsiolkovsky crater shows more mafic, mare-basaltic composition relative to its surrounding anorthosetic highlands. Impact ejecta of Picard crater that is located even in the mare basin reveals remarkably mafic composition in comparison to the average composition of Mare Crisium. The effective spatial resolution of the Apollo XRF map is less than 30km after compilation of data obtained from several orbits.

The SELENE mineralogy and elemental composition mapping also aims at identification of materials from deep interior when observing the central peaks of craters and impact ejecta. Global regional variation of base rock composition will be informed as well as exposed mantle materials at some areas. Investigation of crust and mantle differentiation processes, evolution of lunar highland crust, and magnesium number of the lower crust and mantle will be the main targets.

Instruments: The XRS onboard SELENE [2-4] mainly aims at global mapping of major elemetns, with a footprint of 20km by 20km.

The XRS instrument consists of a main detector to observe X-rays off the lunar surface, XRF-A, a direct solar X-ray monitor and an onboard XRF calibrator with standard sample, SOL-BC, and the electronics, XRS-E. The specification is tabulated in Table 1.

To achieve the scientific objectives, we adopted new technologies such as X-ray charge-coupled devices (1-inch square sized, 1K by 1K pixels, full-frame transfer method, buttable shape, manufactured by Hamamatsu Photonix, K.K.), ultra-thin beryllium window in 5 to 10 micron thick, latticed collimators to limit the FOV in 12 x 12 deg, advanced thermal design to keep CCD chips sufficiently cool with passive radiation, and the 60MHz and 32 bit fast RISC-type onboard computer, SH-OBC, of voting majority technique to improve radiation tolerance. The XRS has higher energy resolution of 150 to 180 eV at 5.9KeV (depending on chips), and large detection area of 100cm^2 by using array of 16 CCD chips. Since the allocation of telemetry is limited in 4Kbytes/sec for the XRS in nominal mode, the XRS has functions to extract only X-ray events from all the readout data from CCD at 125KHz, to classify the grade for each X-ray event, and to produce X-ray energy spectrum by using the onboard logic circuits of FPGA and the software program in the SH-OBC.

Current Status around the Lunar Orbit: We have checked the XRS in its function of electronics, power supply, and thermal control in the lunar transfer orbit in 24 Septemper 2007. After insertion into the lunar polar circular orbit, we conducted the examination of detector sensitivity and onboard data handling functions of FPGA logics and the software.

The basic functions of the XRS showed good performance. But we found the CCD detector has larger numbers of unproper events than expected, possibly which occurred from the defects of CCD chips and by the impacts of high energy cosmic rays. The XRS has experienced more severe radiation condition than designed. The mission desided to change from the direct LOI to 2.5 phasing orbits before LOI, so that it passed terrestrial radiation belt three times. The XRS is now operated in the reduced mode, in which limited numbers of CCD chips are driven to read the data faster. This means the effective detrection area becomes a quarter or a half of origianl one, but the signal to backgrounds ratio becomes good enough for observation due to shorter integration time. Further optimization of CCD operation is necessary to achieve full performance in the lunar orbit.

However, X-ray data from the Moon and from the onboard standard sample successfully obtained. The X-rays off the standard sample detected by SOL-C shows X-ray spectrum with Mg-, Al-, and Si-Kα, and in some times with Ca- and Fe-Kα. The X-ray flux shows in good correspondense with that of GOES (Geostationary Orbiting Environmental Satellite) X-ray monitor. For the XRF-A data from the lunar surface, clear enhancement of the X-ray flux shows just on the time correspondingly to the increase of flux of SOL-C.

The XRS observation is highly dependent on the solar activity, which has been in the solar minimum in 2007 and the X-ray activity has been in very low level (under A0-Level). Furthermore, the beta angle (the angle of the Sun to the center of the Moon to the spacecraft) is rather high so that the incident angle of solar X-rays is larger than 60°, which is under unproper condision for XRF spectrometry. Therefore quantitative elemental composition is yet to be obtained so far.

One thing we obtained as compared to the laboratory experiments is that reduction of XRF excitation was found at a relative ly large phase angle (the angle from the Sun to the lunar surface to the detector) by several to an order of magnitude. This is typical phenomenon of XRF at the sandy surface like lunar regolith [5].

In 2008, the next solar sycle has begun and solar activity appears to enhance with some occurrences of C-class solar flares. After February, the beta angnle condition becomes suitable for XRF spectrometry. The elemental determination and its mapping will be expected to start at that time.

References:

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Table 1. Specification of the XRS

	XRF-A Lunar XRF Detector	SOL-B Solar X-ray Monitor	SOL-C XRF Calibrator
Detector	2D Si-CCD x 16chips Hamamatsu Photonix	SiPIN diode x 2 AMPTEK	2D Si-CCD x 1chip Hamamatsu Phtonix
Detection Area	100 cm^2	Pinhole	6 cm^2
Fields of View	12 x 12 deg	Hemispherical	Hemispherical
Footprint Resolution	20km @100km altitude	N/A	N/A
Energy Range	1 – 10 KeV	1 – 20 KeV	1– 10 KeV
Energy Resolution	< 180eV @Fe55	< 250eV @Fe55	< 180eV @Fe55
Operation Temperature	< -40 degC	< -20 degC	< -40 degC
A/D Conversion	12bits	8bits	12bits
Telemetry Modes	Spectrum, Image	Spectrum	Spectrum, Image
Other Resources: Total Mass Total Power Total Telemetry Rate CPU and RAM	 21Kg (XRF-A: 9.0Kg, SOL-B/C: 4.5Kg, XRS-E: 7.5Kg) 46W (nominal operation mode) 32Kbps (nominal operation mode. 3.2Kbps for BG mode) Super-Hitachi SH-3 OBC (16MHz), 256KB-EEPROM, 8Mbytes-DRAM		