**X-RAY FLUORESCENCE SPECTROMETER ONBOARD THE SELENE LUNAR ORBITER: ITS SCIENCE AND INSTRUMENT.** T. Okada[1,2], K. Shirai[1], Y. Yamamoto[1], T. Arai[1,3], K. Ogawa[1,4], and M. Kato[1,2,4], [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshino-dai, Sagamihara, 229-8510 Japan, okada@planeta.sci.isas.ac.jp), [2]Department of Earth and Planetary Science, Univ. of Tokyo (7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033 Japan), [2]Department of Space and Astronautical Science, The Graduate University for Advanced Studies (3-1-1 Yoshino-dai, Sagamihara, 229-8510 Japan), [4]Department of Earth and Planetary Sciences, Tokyo Institute of Technology (2-12-1 Ookayama, Meguro-ku, Tokyo, 152-8550 Japan).

**Introduction:** We have been developing an X-ray fluorescence spectrometer, XRS, for the SELENE mission to map major elemental composition of the Moon as well as to understand the mechanism of X-ray excitation in the nightside and physical properties caused by surface materials[1-2]. We present here scientific objectives and instrumentation of the XRS, since a critical design review has been finished and the flight model is in preparation.

The SELENE (SELenological and ENgineering Explorer) mission is a lunar polar orbiter organized by the ISAS/JAXA to be launched in 2006 and conducts global mapping of composition, geology, surface and subsurface structure, gravity, and magnetic fieled as well as studying plasma physics of lunar environments. Mission duration is scheduled to conduct in calibration phase for two months, nominal mission phase for ten months, and extended mission phase for six months.

We have experience in development of X-ray spectrometers based on charge-coupled devices for the S310-28 sounding rocket experiment in 1999 and Hayabusa (or MUSES-C) that was launched in 2003, will rendezvous S-class asteroid Itokawa(25143) and conduct remote observation, and will return samples in 2007[3]. The XRS instrument onboard the SELENE is basically in similar concept to that of Hayabusa, but has redesigned most suitable for lunar mission and improved its performance.

**Scientific Objectives of the XRS:** There are many scientific objectives using the XRS observation, including determination of major elemental composition in the dayside, understanding mechanism of X-ray excitation in the nightside, and investigating physical properties caused by surface roughness and mineralogy.

Major elemental composition is among the most fundamental information about the lunar science. As was proven during the Apollo 15 and 16 missions, major elemental composition are determinable through X-ray fluorescence spectrometry from the orbiter, since solar X-rays sufficiently excite the fluorescent X-rays characteristic of major elements. Apollo missions have mapped major elemental ratios of Mg/Si and Al/Si at 9% of the lunar surface in equatorial region [4]. The SMART-1, an engineering demonstration mission by ESA and now in cruise to the Moon by electric propulsion, also carries an X-ray spectrometer based on newly developed swept-charged devices [5]. It will conduct elemental mapping from the altitude of several hundred to thousands kilometer, enough to investigate planetary-scale to basin-scale variation of major elements.

As for the SELENE mission, the spatial resolution for major elements is desired within 20km for the entire lunar surface except for the polar regions. Elemental maps in such a spatial resolution are helpful for studying the growth and evolution processes of lunar maria, since characterization and classification of each lava flow is expected. Much progress should be also achieved in constructing models of formation and evolution of lunar highlands, where has been controversial partly by absence of elemental data.

With further spatial resolution achieved analytically by compilation of data from orbit to orbit, for example within 10km resolution, it becomes possible to investigate local but very specific sites of scientific interest such as the insides of the impact craters, volcanic features, and dark deposits. Crater floors and surrounding ejecta show the characteristics of materials at the local deep layers. Central peaks of crater expose the materials from deeper layer. Lava flows and dome features exhibit the volcanic processes happened at each era.

Mechanisms of X-ray excitation in the nightside of the Moon have been considered, but await quantitative understanding with *in situ* observation. In addition to X-ray spectrometer, the SELENE carries instruments of plasma wave, particle, and magnetic field. Concurrent observation should play role for that purpose.

It should be noted that the lunar regolith takes effect in both of intensity and spectral profile of X-ray fluorescence. Investigation of such phenomena and physical properties must improve analytical method to make corrections for the observation data.

Mineral size effect shows the difference between ideal homogeneous material and in-real finite-sized mineral compounds such as lunar regolith, which is understood by alteration of typical absorption depth of incident X-rays. Particle size effect reveals the difference of phase functions of powdered or rough surface, relative to ideal flat surface, which is dominantly caused by shading of incident X-rays and shielding of emission X-rays.

**Instrumentation of the XRS:** The XRS consists of main lunar surface X-ray detector, XRF-A, and solar X-ray monitor, SOL-BC, and electronics and interfaces, XRS-E. Specifications of the XRS instrument are tabulated in Table 1.

XRF-A carries 16 chips of Hamamatsu Deep-1 type front-illuminated 2-dimensional CCDs, which has 1-inch square of detection area and adopts full-frame-transfer method [6]. It consists of 4 units of CCD chips arrayed 2 by 2 to have 100 cm2 in total detection area. In front of the CCDs are equipped 5-micron thick Beryllium windows for light-tight and high transparency of soft X-rays, as well as 3mm-pitch latticed collimators for limitation of detection fields of view within 15deg. To reduce thermal noise production, CCD temperature remains below 210K with passive radiation cooling, except for only short periods of the mission.

SOL-BC has two direct solar monitors based on AMPTEK XRT PIN photodiodes, SOL-B, and a CCD-based X-ray fluorescence calibrator with the onboard standard sample, SOL-C. The direct monitors show the high temporal resolution and point in the northern and southern hemispheric directions, respectively. The XRF calibrator carries a single CCD chip points to the standard sample of a glassy plate in lunar basaltic composition. Detectors are sufficiently cooled with radiation cooling as well as thermoelectric cooling system installed inside each detector.

XRS-E consists of a Hitachi onboard computer TC-OBC operating 3-CPUs to judge by voting majority that controls all the XRS system, and conducts command/telemetry interfaces with the satellite data management system, power supply unit, heater control unit, and those electronics to drive detectors, high voltage, and data acquisition and handlings. The electronics has miniaturized by adopting programmable gate arrays and hybrid ICs for conducting onboard data processes.

Data from CCDs should be effectively processed into realistic amount of telemetry downlink, by use of the onboard functions of X-ray event extraction, real-time background calculation, and area selection. After the hardware processes, the software installed in TC-OBC further detailed processes and analyses including error data rejection, grade judgment and classification, histogram production, data compression. The software also has functions to operate the XRS observation in selective programmed sequential patterns.

**Current Status of the XRS:** We have finished the critical design review process early in 2003, and started development of the flight model for the system interface tests. We have examined all the designed functions of the XRS and electromagnetic compatibility, as the instrument self-preparation. The system interface tests have begun in September, 2003 to confirm command and telemetry interface with the satellite and mutual interference with satellite and other instruments. Then, electromagnetic compatibility of all the satellite system has been checked under the considered conditions of satellite operation.

After finished the interface tests in February, 2004, each instrument is now in self-integration and calibration phase. We should examine final function tests, conduct detailed measurements of dependency upon temperature or profiles against parameters to set, and improve performance for X-ray detection by selection and adjustment of each parameter.

**References:**

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**Table 1: Specifications of the XRS**

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| Total Mass | 23.5 kg |
| Total Power | 40.4 W |
| Telemetry Rate | 32 Kbps |
| Detection Area | 100 cm2 |
| Energy Range | 0.7 – 10 KeV |
| Energy Resolution | 150 eV @ 5.9KeV |
| A/D Conversion | 12 bit |
| Field of View (50%) | 12 x 12 deg |
| Operation Temperature | 200 - 210 K |

**Figures: XRF-A (Up) and SOL-BC (Low)**