will eliminate most events due to charged particles, gamma rays produced by cosmic rays incident on the spacecraft, and Compton-scattered events in the crystal. A plastic scintillator over the nadir-pointing surface of the germanium crystal will provide a similar capability in the forward direction without significantly attenuating the gamma ray flux from the Moon. The gamma ray detector will be on a short cantilever to further reduce the background from the spacecraft. One side segment of the cesium iodide shield will serve as a back-up for the germanium crystal.

The critical issue for operating a germanium detector in space is the method of cooling. For short missions, stored cryogens such as liquid nitrogen, solid methane, or solid argon have been proposed. For longer missions a passive radiator, such as used on the Mars Observer, or an active device, such as a Stirling cycle cooler, is required. We propose not to use a passive radiator because of complications in shielding the radiator from the Sun, Earth, and Moon when the spacecraft is in a polar orbit and, instead, propose to use the British Aerospace Stirling cycle cooler based on the Oxford design. This closed-cycle mechanical cooler is designed for magnetic separation of the lunar soils. The critical issue for operating a germanium detector in space is the method of cooling. For short missions, stored cryogens such as liquid nitrogen, solid methane, or solid argon have been proposed. For longer missions a passive radiator, such as used on the Mars Observer, or an active device, such as a Stirling cycle cooler, is required. We propose not to use a passive radiator because of complications in shielding the radiator from the Sun, Earth, and Moon when the spacecraft is in a polar orbit and, instead, propose to use the British Aerospace Stirling cycle cooler based on the Oxford design. This closed-cycle mechanical cooler is designed for magnetic separation of the lunar soils.

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Fig. 1. Schematics of a generic germanium detector with a split-cycle Stirling cooler (adopted from [5]) and the neutron sensors for thermal, epithermal, and fast neutrons.

Magnetic separation is a viable method for concentration of components of lunar soils and rocks for use as feedstocks for manufacture of metals, oxygen, and for recovery of volatiles such as \(^3\)He [1].

Work with lunar materials indicates that immature soils are the best candidates for magnetic beneficiation [2]. The magnetic susceptibility at which selected soil components such as anorthite, ilmenite, or metallic iron are separated is not affected by soil maturity, but the recovery of the concentrated components is. Increasing soil maturity lowers recovery [3]. This is illustrated in Fig. 1.

Mature soils contain significant amounts of glass-encased metallic iron. Magnetic susceptibility, which is sensitive to metallic iron content, can be used to measure soil maturity. The relationship between the ratio of magnetic susceptibility and iron oxide content and the conventional maturity parameter, \(1/\text{FeO}\), ferromagnetic resonant intensity divided by iron oxide content, is given in Fig. 2. The magnetic susceptibilities were determined using apparatus designed for magnetic separation of the lunar soils.

Magnetic separation should be incorporated in the instrumentation packages carried by lunar landers and rovers for in situ identification of candidate soils best suited for magnetic benefi-
The quickest, lowest-cost lunar resource assessment program: integrated high-tech earth-based astronomy.

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Introduction and Recommendations: Science and technology applications for the Moon have not fully kept pace with technical advancements in sensor development and analytical information extraction capabilities. Appropriate unanswered questions for the Moon abound, but until recently there has been little motivation (funding) to link sophisticated technical capabilities with specific measurement and analysis projects. Over the last decade enormous technical progress has been made in the development of (1) CCD photometric array detectors, (2) visible to near-infrared imaging spectrometers, (3) infrared spectroscopy, (4) high-resolution dual-polarization radar imaging at 3.5, 12, and 70 cm, and equally important, (5) data analysis and information extraction techniques using compact powerful computers. Parts of each of these have been tested separately, but there has been no programmatic effort to develop and optimize instruments to meet lunar science and resource assessment needs (e.g., specific wavelength range, resolution, etc.) nor to coordinate activities so that the symbiotic relation between different kinds of data can be fully realized. No single type of remotely acquired data completely characterizes the lunar environment, but there has been little opportunity for integration of diverse advanced sensor data for the Moon.

Recommendation. A research and analysis program to survey potential resource sites on the lunar nearside is recommended that would include aggressive instrument development and acquisition and analysis of advanced sensor data obtained for the Moon with optical, infrared, and radar telescopes. Coordinated acquisition and integration of advanced sensor data can provide synoptic information necessary to assess regional compositional diversity, local regolith character, and geologic context of sites on the lunar nearside that have high potential for lunar resources. The cost of such an R&A program is estimated to be about $5 million per year. This program includes an instrument development and upgrade program during the first year, and calibration and initial data products by the second year. The broad nature of the program exercises expertise gained during and since Apollo and provides...