DEVELOPING THE GLOBAL EXPLORATION ROADMAP: EXPANDING THE "LUNAR VICINITY" SCENARIO. C. R. Neal[1], G. Schmidt[2], I. A. Crawford[3], P. Ehrenfreund[4] [1]Dept. Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556 USA (neal.1@nd.edu), [2]SSERVI, NASA Ames Research Center, Moffett Field, CA, USA (gregory.k.schmidt@nasa.gov), [3]Department of Earth and Planetary Science, Birkbeck College, University of London, UK (i.crawford@ucl.ac.uk), [4]Elliott School of International Affairs, George Washington University, Washington DC 20052 USA (pehren@gwu.edu).

Introduction: The Gobal Exploration Roadmap (GER, [1]) has been developed by the International Space Exploration Coordination Group (ISECG – comprised of 14 space agencies) to define various pathways to getting humans beyond low Earth orbit and eventually to Mars. Such pathways include visiting asteroids or the Moon before going on to Mars. This document has been written at a very high level and many details are still to be determined.

In this presentation, we focus on developing the GER "Lunar Vicinity" scenario by mapping a number of recent reports/documents into the GER. These documents are in no way meant to be encompassing everything that is relevant to this process (indeed, others can and should be added, such as the soon to be published JAXA Space Exploration Roadmap). This exercise is intended to demonstrate that existing documents can be mapped into the GER despite the major differences in granularity, and that this mapping is a way to promote broader national and international buy-in to the GER.

The documents used here are: the Committee on Space Research (COSPAR) Panel on Exploration report on developing a global space exploration program [2], the Strategic Knowledge Gaps (SKGs) report from the Lunar Exploration Analysis Group (LEAG) [3], the Lunar Exploration Roadmap developed by LEAG [4], the National Research Council report Scientific Context for the Exploration of the Moon (SCEM) [5], the scientific rationale for resuming lunar surface exploration [6], and the astrobiological benefits of human space exploration [6,7].

A Summary of the Global Exploration Roadmap: The common goals as articulated in [1] are as follows:

- Develop Exploration Technologies & Capabilities.
- Engage the Public in Exploration.
- Enhance Earth Safety.
- Extend Human Presence.
- Perform Science to Enable Human Exploration.
- Perform Space, Earth, and Applied Science.
- Search for Life.
- Stimulate Economic Expansion.

With Mars being the goal there are three paths articulated - Exploration of a Near-Earth asteroid; Extended Duration Crew Missions; and Humans to the Lunar Surface. The GER gives 5 goals for the Lunar Surface scenario:

- Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).
- Characterizing human health and performance outside Earth's magnetosphere and in a reduced gravity environment.
- Conducting high priority science benefiting from human presence, including human-assisted lunar sample return.
- Advance knowledge base related to use of lunar resources.
- Explore landing sites of interest for extended durations.

The Mapping Process: For this activity, we did not try and map directly to the GER, but rather focused on important lunar science and exploration topics. Two example are reported here (and more will be presented at the workshop): Polar Volatiles and Technology Test Bed/Human Health.

1. Polar Volatiles: The discovery of volatile deposits at the lunar poles brought these areas into focus for future human exploration. The GER goal "Advance knowledge base related to use of lunar resources" certainly is important for this subject. The other documents [2-7] are detailed below using their reference number.

COSPAR [2]. Support studies and precursor activities toward "International human bases"; Sample return missions to the Moon, near-Earth asteroids and Mars.

LEAG-SKGs [3]. Composition/quantity/distribution/ form of water/H species and other volatiles associated with lunar cold traps:

- Map & characterize broad features of polar cold traps;
- Determine lateral & vertical extent of polar volatiles;
- Processes and history of water and other polar volatiles.

LEAG-LER [4]. Objective Sci-A-3: Characterize the environment and processes in lunar polar regions and in the lunar exosphere.

SCEM [5]. Priority 4 - The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.

Scientific Rationale [6]. The Moon is the type locailty to study volatile loss, transport, and retention on airless bodies; the polar deposits represent targets for in situ resource applications;

Astrobiology [6,7]. It is possible that some information concerning the importance of comets in ''seeding'' the terrestrial planets with volatiles and prebiotic organic materials. Lunar polar icedeposits will have been continuously subject to irradiation by cosmic rays and, as such, may have played host to organic synthesis reactions of the kind thought to occur in the outer Solar System and on interstellar dust grains.

2. Technology Test Bed/Human Health: The Moon represents a key asset for testing planetary exploration technologies and understanding the effect of the space exploration on human health because of its proximity to Earth and its hostile environment. The GER is quite expansive about such issues listing three main goals:

- Develop Exploration Technologies & Capabilities.
- Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).
- Characterizing human health and performance outside Earth's magnetosphere and in a reduced gravity environment.

The test documents [2-7] map to these in the following ways.

COSPAR [2]. Synergies of robotic/human exploration; Robotic Village concept of ILEWG and ILRP.

LEAG-SKGs [3]. There are many SKGs highlighted that relate to this topic and these are: Solar event prediction; Radiation at the lunar surface; Biological impact of dust; Maintaining peak human health; Radiation shielding; Dust and Blast ejecta; Surface Trafficability; Plasma environment and charging.

LEAG-LER [4]. This roadmap is forward looking in that it proposes to use the Moon to go elsewhere. As such there are several goals and objectives that relate directly the technology and human health:

- **Objective Sci-A-4**: Understand the dynamical evolution and space weathering of the regolith;
- **Objective Sci-B-2**: Regolith as a recorder of extra-lunar processes;
- **Objective Sci-D-9**: Investigate the production of oxygen from lunar regolith in lunar gravity;
- **Objective Sci-D-14**: Study the fundamental biological and physiological effects of the integrated lunar environment on human health and the fundamental biological processes and subsystems upon which health depends;
- **Objective Sci-D-15**: Study the key physiological effects of the combined lunar environment on living systems and the effect of pharmacological and other countermeasures;
- **Objective Sci-D-16**: Evaluate consequences of long-duration exposure to lunar gravity on the human musculo-skeletal system;
- **Goal FF-A**: Identify and test technologies on the Moon to enable robotic and human solar system science and exploration.
- **Goal FF-B**: Use the Moon as a test-bed for missions operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.
- **Goal FF-C**: Preparing for future missions to other airless bodies.

SCEM [5]. While this report focused on lunar science, understanding the pristine lunar environment is important for designing mitigation technologies in order to provide safe living and working conditions. Therefore the SCEM maps into this through "Priority 8 - Processes involved with the atmosphere & dust environment of the Moon are accessible for scientific study while the environment is in a pristine state."

Scientific Rationale [6]. This document states in several places the importance of using the Moon to understand the effects of the space environment on human health, such as 1) Monitoring human adaptation to prolonged exposure to partial gravity may offer significant insights into vestibular disorders and a range of processes beyond associated in aging, disusepathology and lifestyle conditions such as the metabolic syndrome and cardiovascular disease; and 2) There would be much to learn about life support (e.g., bio-regenerative food, breathable air, and water closed-loops), and medical support provision, from human operations in a lunar base beyond research into partial gravity effects.

Astrobiology [6,7]. Use of the Moon to understand the long-term effects of the space environment (e.g., the radiation, microgravity, psychological aspects) is required because our knowledge is not sufficient. Several areas of investigation are highlighted:

- Study of the adaptation of terrestrial life to the lunar environment.
- Use of the lunar environment for panspermia experiments and as a test bed for planetary protection protocols.
- Use of the lunar environment as a test-bed for the development of bioregenerative life-support systems, for long-term use on the Moon and future long-duration deep space exploration missions.

Conclusions: There are many documents that describe the challenges and rewards of human space exploration. We have only scratched the surface in examining the "Lunar Vicinity" scenario of the GER, but our major conclusion is that while the GER has very broad goals that define a framework for international cooperation in human space exploration, detail from existing, well-established and community developed documents can be mapped to these goals. By broadening the scope of this mapping project to include other internationally developed documents and individual space agency roadmaps the GER can become an important long range planning document for human space exploration.

References: [1] Global Exploration Roadmap (2013) http://www.globalspaceexploration.org, 50 pp. [2] Ehrenfreund et al. (2012) *Adv. Space Res*. *49*, 2-48. [3] Strategic Knowledge Gaps for the "Moon First" Human Exploration Scenario (2012) http://www.lpi.usra.edu/leag/GAP_SAT_03_09_12.pdf [4] Lunar Exploration Roadmap (2013) http://www.lpi.usra. edu/leag/ler_draft.shtml [5] National Research Council (2007) http://www.nap.edu/catalog/11954.html [6] Crawford et al. (2012) *Planet. Space Sci. 74*, 3-14. [7] Crawford (2010) *Astrobiology 10*, 577-587.