Developing The Global Exploration Roadmap. C. R. Neal[1], G. Schmidt[2], I. A. Crawford[3], P. Ehrenfreund[4], J. Carpenter[5]. [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 (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). [5]ESA-ESTEC, 2201 AZ, Noordwijk, The Netherlands (James.Carpenter@esa.int)

Introduction: The Global Exploration Roadmap (GER, [1]) has been developed by the International Space Exploration Coordination Group (ISECG – comprised of 14 space agencies) to define a pathway to get humans beyond low Earth orbit and eventually to Mars. This document has been written at a high level and many details are still to be determined. However, a number of documents regarding international space exploration can inform this document (e.g. [2,3]).

In this presentation, we focus on developing the "Humans to the Lunar Surface" theme of the current GER [3] by adding detail via mapping a number of recent reports/documents to it. Precedence for this scenario is given by Szajnfarber et al. [4] who stated after the initial GER [2] "We find that when international partners are considered endogenously, the argument for a **"**flexible path**"** approach is weakened substantially. This is because international contributions can make **"**Moon first**"** economically feasible".

The documents highlighted here are in no way meant to be all encompassing and other documents can and should be added, (e.g., the 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 Lunar Vicinity scenario.

The documents used here are: the Committee on Space Research (COSPAR) Panel on Exploration report on developing a global space exploration program [5], the Strategic Knowledge Gaps (SKGs) report from the Lunar Exploration Analysis Group (LEAG) [6], the Lunar Exploration Roadmap developed by LEAG [7], the National Research Council report Scientific Context for the Exploration of the Moon (SCEM) [8], the scientific rationale for resuming lunar surface exploration (SR [9]), the astrobiological benefits of human space exploration [9,10].

A Summary of the Global Exploration Roadmap [1]: The common goals 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.

Three paths are articulated to get to Mars - Exploration of a near-Earth asteroid; Extended duration crew missions; 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).
- Advance knowledge base related to use of lunar resources.
- Characterize human health/performance in a reduced gravity environment beyond Earth's magnetosphere.
- Conducting high priority science benefiting from human presence, (inc. human-assisted sample return).
- Explore landing sites for extended durations.

The Mapping Process: Unlike our previous mapping efforts (Schmidt et al., 2014; Neal et al., 2014), mapping directly to the GER is employed. Two examples are reported here (and more will be presented at the workshop): Polar Volatiles and Technology Test Bed/Human Health.

1. Advance knowledge base related to use of lunar resources: It has been known since the Apollo that the Moon is home to resources that could be used to facilitate human space exploration. Since that time, lunar volatiles have become an intensive topic of lunar research and could form the basis of an important natural lunar resource.

COSPAR [5]. Support the development of evolutionary concepts for making use of local resources to enable sustainable human presence and fruitful operations on the surface of Moon and Mars.

LEAG-SKGs [6]. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps (13 SKGs), for example:

- 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 [7]. Obj. Sci-A-3: Characterize the environment and processes in lunar polar regions & the lunar exosphere. Also in the Feed Forward theme.

SCEM [8]. Priority 4 - The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.

SR [9]. The Moon is the type locality to study volatile loss, transport, and retention on airless bodies; the polar deposits represent targets for in situ resource applications;

ASTROBIO [9,10]. It is possible that some information concerning the importance of comets in ''seeding'' the terrestrial planets with volatiles and prebiotic organic materials can be found. Lunar polar ice deposits will have been continuously subject to irradiation by cosmic rays and 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. Human Health: The major research platform for studying the effects that space exploration can have on human health is currently the International Space Station (ISS). The ISS is not ideal for examining the effects of space radiation (it is within the Earth's magnetic field) or the effects of reduced gravity on human physiology. We have a knowledge base on how the human body reacts to Earth's gravity and at microgravity (from the ISS, etc.), but is there a linear degradation between the two extremes? Long duration human missions to the lunar surface should be able to inform us about this. In addition to the test documents, a recent study highlight the Moon as an ideal place to study the effects of long-duration space exploration [11]. The test documents map to these in the following ways.

COSPAR [5]. The ISS is highlighted as the place where current research is being conducted on the impact the space environment has on human health. highlighted the US NRC Report 2012 [12], where both physical and psychological affects of space exploration are discussed. Finally, this document notes that space radiation is a major barrier to human exploration of the Solar System and concluded that environmental characterization, as well as materials testing should be conducted by robotic precursor missions, and that a focus on space weather prediction should be made.

LEAG-SKGs [6]. Five SKGs were identified 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.

LEAG-LER [7]. Human health is a theme that pervades through the LER:

Objective Sci-D-14: Study the fundamental biological & physiological effects of the 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 lunar environment on living systems & 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.

Objective FF-A-2 and FF-C-8: Develop Crew Health Systems That Enable Safe, Long, Surface Stays.

SCEM [8]. 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*."

SR [9]. This document emphasizes the importance of using the Moon to understand the effects of the space environment on human health: 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.

ASTROBIO [9,10]. 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; 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 (see also [11]).

Conclusions: Our major conclusion is that while the GER has broad goals that define a framework for international cooperation in human space exploration, detail from existing, international & community developed documents can be mapped to these goals. By broadening the scope of this effort to include other internationally developed documents and 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; [2] Logsdon (2008) *Space Pol. 24*, 3-5; [3] Schaffer (2008) *Space Pol. 24*, 95-103; [4] Szajnfarber et al. (2011) *Space Pol. 27*, 131-145; [5] Ehrenfreund et al. (2012) *Adv. Space Res. 49*, 2-48. [6] Strategic Knowledge Gaps for the Moon First Human Exploration Scenario (2012) http://www.lpi.usra.edu/leag/GAP_SAT_03_09_12.pdf [7] Lunar Exploration Roadmap (2013) http://www.lpi.usra.edu/leag/ler_draft.shtml [8] NRC (2007) http://www.nap.edu/catalog/11954.html; [9] Crawford et al. (2012) *Planet. Space Sci. 74*, 3-14. [10] Crawford (2010) *Astrobiology 10*, 577-587. [11] Goswami et al. (2012) *Planet. Space Sci. 74*, 111-120. [12] NRC Report. Research for a Future in Space: The Role of Life and Physical Sciences, 2012 http://www.nap.edu/catalog.php?record_id=13450.