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LUNAR HYDROGEN: A RESOURCE FOR FUTURE USE AT LUNAR BASES AND SPACE ACTIVITIES*

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Hydrogen abundances have been determined for grain size separates of five lunar soils and one soil breccia. More than 80 percent of the hydrogen in lunar soils is found in the sub-45 micron grain size fraction. Abundances of hydrogen in bulk lunar soils and soils from the Apollo 17 deep drill core are directly correlated to the I_S/FeO maturity parameter. The average ^{1}H/^{4}He atom ratio for soils from the deep drill core was 8.5.

With a commitment to the Space Station and the increasing interest in a potential Lunar Base, there is a need to find an extraterrestrial source of hydrogen for consumables and propellants which might be available at a reduced cost. In order to know if usable quantities of hydrogen are present in the near-earth region of space (i.e. on the moon) a study of hydrogen abundances and distributions in lunar materials has been undertaken. An understanding of the potential sources of hydrogen on the lunar surface must be obtained. If such sources of hydrogen can be identified, future space activities will be enhanced by having another source of consumables and propellants available for use. The extreme costs of transporting hydrogen from earth would be reduced if sufficient quantities of hydrogen were available in the near-earth region of space.

Hydrogen is the most abundant element in the cosmos. The sun is constantly burning hydrogen and hydrogen is being lost from the sun. In addition, hydrogen is streaming away from the sun in the form of the solar wind. Hydrogen is the most abundant element in the solar wind. It is known that the lunar surface has been irradiated by the solar wind. From the detailed studies of lunar materials, it has been shown that selected volatile elements present in the solar wind (i.e. H, He, C, N, Ne, Ar, etc.) are enriched on the surfaces of exposed materials. The longer the surfaces of the samples are exposed to the solar wind the greater the amounts of solar wind species trapped in the lunar materials.

In order to understand the hydrogen abundances and distributions in lunar materials we have been making hydrogen measurements in a wide variety of soils, grain size separates, breccias, igneous rocks along with samples from the deep drill cores. A microanalysis technique utilizing helium ionization equipped gas chromatography was employed for measuring hydrogen released by pyrolysis from milligram quantities of soils (Carr et al., 1988). Our studies have shown that essentially 100 percent recovery of the implanted solar wind hydrogen can be obtained by heating the soil samples at 900 °C.

Hydrogen abundances measured (Table 1) in five bulk soils range from 26 to 54 μgH/g (within the previously reported by DesMarais et al., 1974), the lowest abundance found being that of the submature soil 71501. The hydrogen abundances calculated from the mass fractions are in excellent agreement with those found experimentally for the bulk samples. For the five soils studied in detail, over 80 percent of the hydrogen is found in the sub-45 micron size fraction. Apollo 15 soil breccia 15086 was disaggregated by freeze-thaw and ultrasonic into its different size fractions. Mass balance calculations for the hydrogen content of the breccia were in good agreement with the experimentally determined value for the bulk sample (58 and 60 μgH/g respectively). In the case of the soil breccia 95 percent of the hydrogen is in the sub-45 micron fraction. A comparison of the I_S/FeO (a maturity indicator) and hydrogen abundance value for 15086 with lunar soils shows that the soil breccia lies off the expected trend. The soil breccia has been enriched in its hydrogen contents as compared to lunar soils of similar maturity.

In order to show that lunar hydrogen abundances are related to soil maturity and exposure histories and not a function of depth within the lunar surface, we have analyzed soil samples from the Apollo 17 deep drill core (70002-70009) (Gibson et al., 1988). The core was taken about 400 meters southeast of Camelot Crater and was the deepest soil column (295 cm) returned from the moon. The I_s/FeO profile for the entire core shows a wide range of soil maturities. The correlation between hydrogen abundance determined in this study and soil maturity as measured by the I_s/FeO index is striking (Figure 1). One of the distinctive features of the core is the immature zone between 20 and 60 cm. As expected, we found very low hydrogen concentrations in this zone. Proceeding down the core, soils became more mature, and larger hydrogen abundances were found. Both of these results are expected from the grain size distributions in the core (Langevin and Nagle, 1980). The section of the core where hydrogen is depleted (bottom of 70009 through 70008) consisted of coarse-grained basaltic material. Gas concentrations are usually lower in larger grain sizes. The largest hydrogen abundances were found in the middle of 70006 down to the middle of 70005. These enrichments are associated with the finer-grained materials which have had a longer surface exposure.

It is important to know the H/He ratio in lunar materials in order to understand the solar abundances along with obtaining information about the potential abundances of helium if use of the ^{3}He is ever to be utilized in fusion processes associated with space activities. Stoenner et al. (1974) measured hydrogen and helium abundances on nine samples from the Apollo 17 deep drill core. They found unusually high H/He ratios for the samples. It is believed that the hydrogen abundances reported by them represent a component of terrestrial water contamination. Using our hydrogen abundances and the helium values of Stonner et al., the average ^{1}H/^{4}He ratio for the Apollo 17 deep drill core was found to be 8.5. This is in the expected range of 7 to 10 for the solar wind ^{1}H/^{4}He atom ratio.

Our hydrogen abundance studies have provided important baseline information for engineering models undergoing study at the present time. From our studies it appears that there is sufficient hydrogen present in selected lunar materials which could be recovered to support future space activities. It is well known that hydrogen can be extracted from lunar soils by heating between 400° and 800 °C. Recovery of hydrogen from regolith materials would involve heating with solar mirrors and collecting the released hydrogen. In order to have an understanding of the magnitude or size of the hydrogen recovery process required to recover sufficient hydrogen for space operations, we are reminded that the Space Shuttle requires around 102,000 kg hydrogen for lift-off from its launch pad on earth. Extraction of hydrogen from a mature lunar soil typical of some of those present at the Apollo 11 or 17 sites would require processing a quantity of soil equal to that found from an area the size of 28 football fields mined to a depth of 10 feet. In comparison to mining operations found on the earth, such mining operations are considered quite small.

Current baseline models for the lunar base are requiring the production of 1000 metric tons of oxygen per year. From this requirement it follows that around 117 metric tons per year of hydrogen would be required for the production of water. Gerisch (1988) has recently examined the equipment requirements for a lunar strip mining system. To support the recovery of 117 metric tons of hydrogen per year, it has been shown that the three drum slusher type of mining equipment could meet the production requirements. The delivery weights of such equipment to the lunar surface would be around 30,000 kilograms. These weights are compatible with shuttle payload capabilities. Gerisch (1988) moted that the three drum cable-way scraper-bucket or slusher mining system could be a viable system for lunar mining operations. Such a system could mine the regolith materials required for hydrogen production on the lunar surface. The ability to obtain hydrogen from the lunar regolith would assist in lowering the operating costs of any lunar base.

References

Carr, R.H. et al. (1988) Analytical Chim. Acta (in press)

DesMarais, D.J. et al. (1974) Proc. 5th Lunar Sci. Conf., 1181-1190.

Gerisch, R.E. (1988) in Space Resources, NASA-ASEE Summer Study held at the California Space Institute, 1984. (in preparation).

Gibson, E.K. Jr., et al. (1988) Lunar and Planet. Sci. XIX, 387-388.

Langevin, Y. and Nagle, J.S. (1980) Proc. 11th Lunar and Planet. Sci. Conf., 1415-1434.

Stoenner, R.W. et al. (1974) Proc. 5th Lunar Sci. Conf. 2211-2229.

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TABLE 1

Hydrogen Abundances of Lunar Soil Size Fractions and Mass Balance Calculations

	10084,149			12070,127			15021,2		
Size Fraction (µm)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)
20	146.7	25.78	37.8	107.4	22.35	24.0	128.5	23.02	29.6
20-45	39.7	18.33	7.3	30.1	17.34	5.2	51.1	22.96	11.7
45-75	24.4	15.01	3.7	16.2	14.82	2.4	22.4	15.61	3.5
75-90	20.1	5.01	1.0	9.0	5.09	0.5	20.8	4.37	1.1
90-150	20.2	12.24	2.5	8.7	13.37	1.2	15.5	13.26	2.1
150-250	11.3	9.06	1.0	7.5	10.60	0.8	8.4	9.25	0.8
250-500	15.7	8.73	1.4	9.4	8.80	0.8	8.2	7.23	0.6
500-1000	7.2	5.82	0.4	8.5	7.63	0.6	11.0	3.31	0.4
Total Hydrogen Calculated in Bulk (µg/g)	55.1			35.5			49.8		
Total Hydrogen Found Experimentally in Bulk (µg/g)	54.2			39.2			49.6		

	60501,1			71501,138		
Size Fraction (µm)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)
20	124.1	24.12	29.9	126.4	17.62	22.3
20-45	43.0	17.76	7.6	47.2	17.67	8.3
45-75	16.1	13.48	2.2	18.5	15.60	2.9
75-90	12.8	4.40	0.6	9.4	4.42	0.5
90-150	9.6	11.54	1.1	7.7	14.75	1.1
150-250	5.2	9.72	0.5	2.0	11.51	0.2
250-500	4.4	10.75	0.5	2.4	10.69	0.3
500-1000	2.6	8.22	0.2	1.7	6.64	0.1
Total Hydrogen Calculated in Bulk (µg/g)	42.6			35.7		
Total Hydrogen Found Experimentally in Bulk (µg/g)	35.8			25.7		

	15086,202 Breccia		
Size Fraction (µm)	Hydrogen Content (µg/g)	Weight %	Hydrogen Calculated in Bulk Soil (µg/g)
20	176.3	28.62	50.5
20-45	21.9	19.05	4.2
45-90	11.7	18.30	2.1
90-150	4.0	12.55	0.5
150-250	2.3	9.12	0.2
250-500	2.7	7.51	0.2
500-1000	1.9	4.85	0.1
Total Hydrogen Calculated in Blut (µg/g)	57.0		
Total Hydrogen Found Experimentally in Bulk (µg/g)	60.4		

APOLLO17 DEEP DRILL CORE

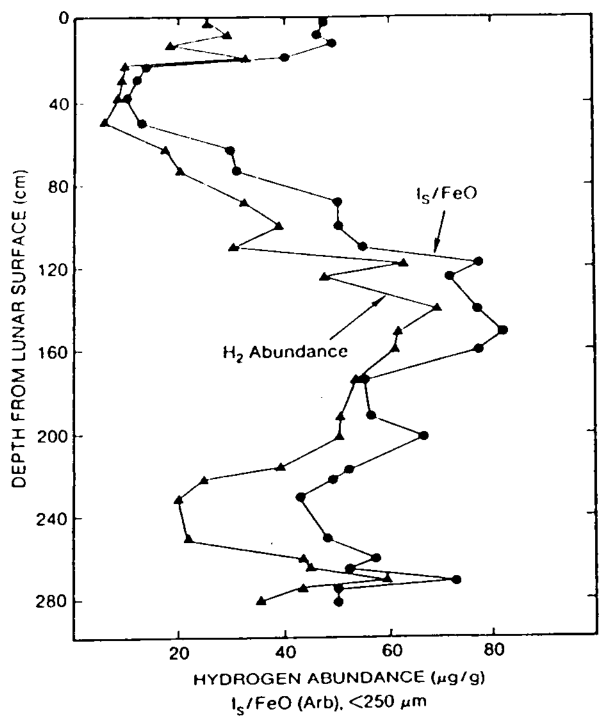

Figure 1. Hydrogen Abundances and I_s/FeO Values for Apollo 17 Deep Drill Core.

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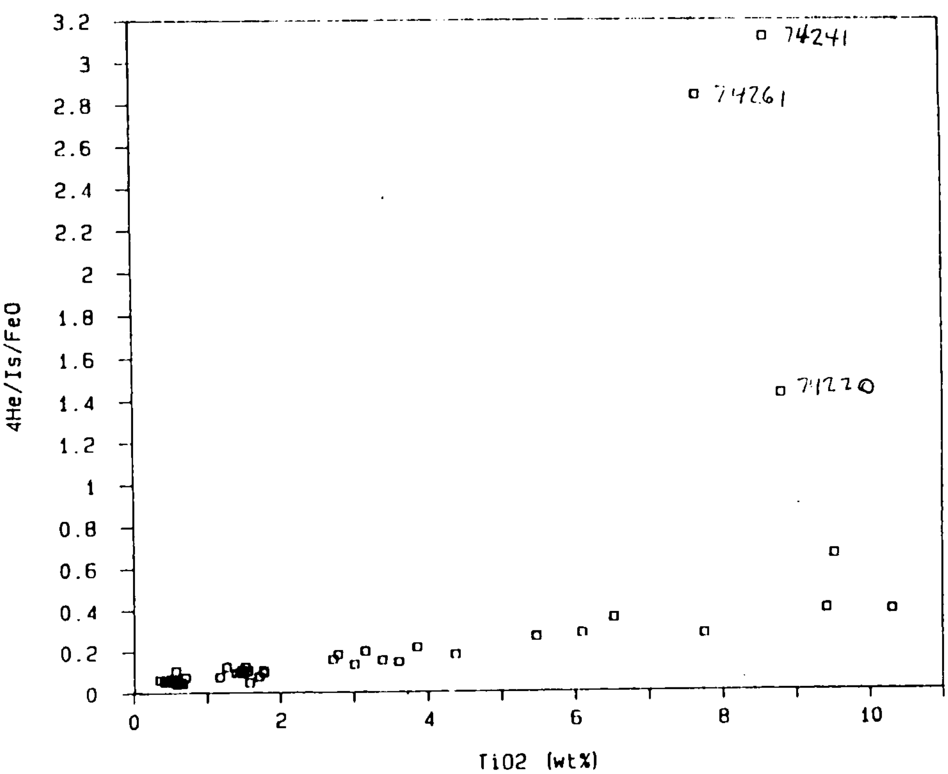
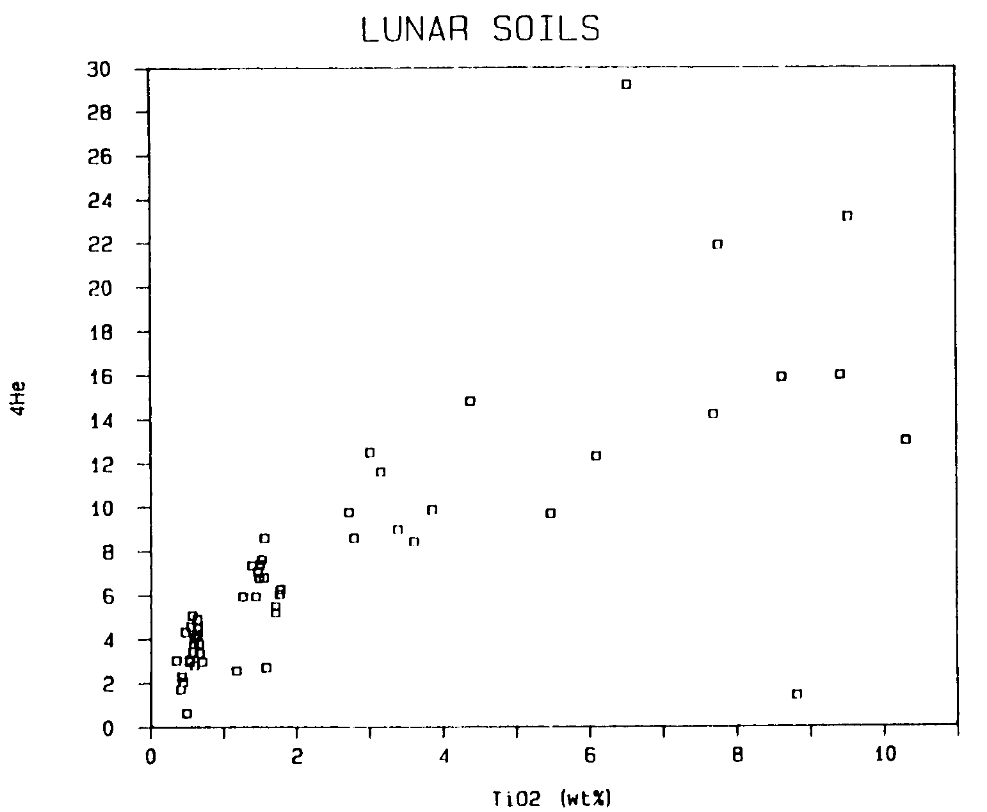
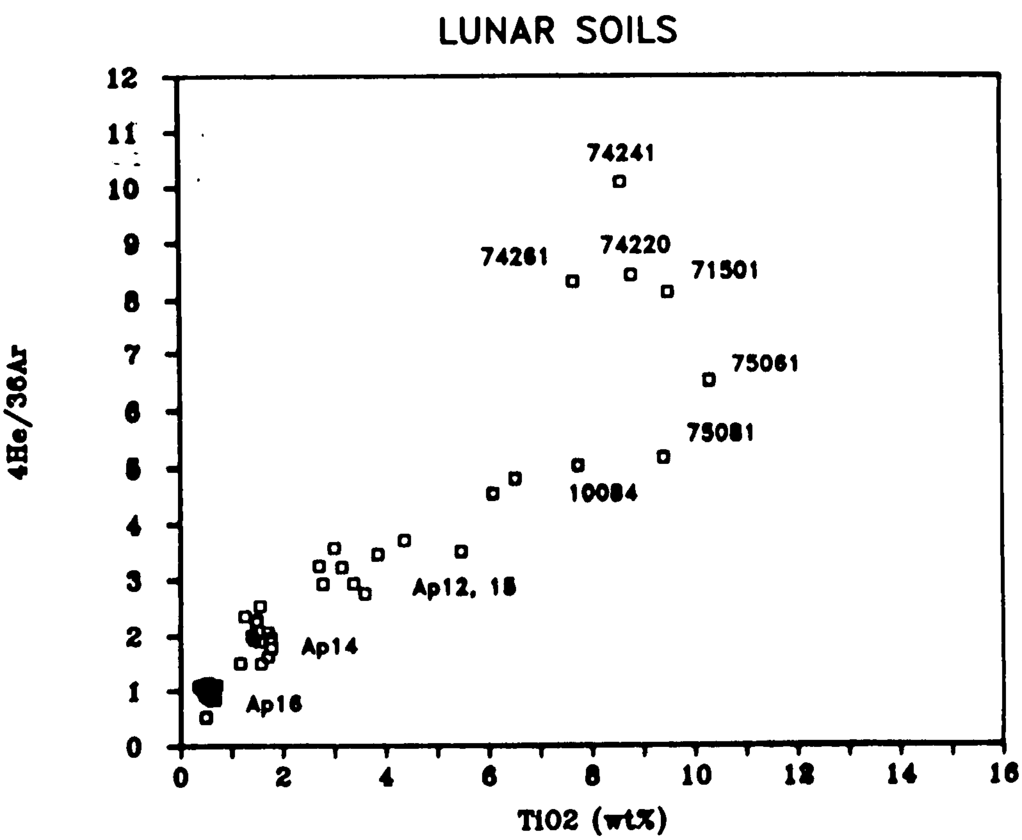
LUNAR SOILS





LUNAR SOILS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
4He
0
2
4
6
8
10
TiO2 (wt%)



LUNAR SOILS
12
11
10
9
8
7
6
5
4
3
2
1
0
4He/36Ar
74241
74261
74220
71501
75061
75081
10084
Ap12, 15
Ap14
Ap16
0
2
4
6
8
10
12
14
16
TiO2 (wt%)

No. 14-09-0070-1228

INTERAGENCY AGREEMENT
BETWEEN THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
AND THE
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

ARTICLE I -- PURPOSE

The purpose of this Agreement between the Bureau of Mines (BOM) of the Department of the Interior and the National Aeronautics and Space Administration, Johnson Space Center (JSC), is to define the research and development areas of mutual interest, and to provide opportunity for cooperative programs in space exploration and establishing permanent lunar bases, as authorized by Section 601 of the Economy Act of June 30, 1983, as amended (31 USC §1535), and Section 203(C) (5) and (6) of the National Aeronautics and Space Act of 1985, as amended (42 USC §2473).

The Agreement will insure full and effective use of the capabilities and expertise of DOI/BOM and NASA/JSC to identify, plan, execute, and monitor space program elements involving rock mechanics, mining, and resource extraction technology. The cooperation between the agencies is agreed to extend from mutual consultation to specific research and development tasks in the indicated areas of science and technology.

ARTICLE II -- PROGRAM COORDINATION

DOI/BOM and NASA/JSC shall implement a regularly scheduled exchange of planning and development of information related to areas of DOI/BOM involvement in space exploration and utilization. These exchanges can be in terms of written or verbal communications, mutual visits, or through joint committee meetings. Each agency will designate a key person to act as a liaison for this interagency cooperative effort.

ARTICLE III --NASA/JSC CONTRIBUTION

A. NASA/JSC will provide the necessary information on the past accomplishments, current activities, and future plans on the lunar base and planetary exploration programs as related to DOI/BOM involvement. NASA/JSC will also provide, as necessary, lunar and planetary samples and environmental data for further DOI/BOM and NASA/JSC cooperative investigations. In addition, NASA/JSC will also provide data on lunar and planetary samples for further property and fragmentation studies.

B. Extraterrestrial samples of NASA/JSC are not committed by this Agreement. Normal NASA/JSC procedures will be followed for access to samples including technical reviews of proposed work and specific security plans for safeguarding samples. NASA/JSC will collaborate with DOI/BOM to identify best samples for specific studies.

ARTICLE IV -- DOI/BOM CONTRIBUTION

Based on the input from NASA/JSC, DOI/BOM will provide technical support for both inhouse and contract research and development related to rock and regolith sampling, mining, mineral extraction, and property determination. Based on input from NASA/JSC, DOI/BOM, will provide technical support for research and development activities related to rock and regolith sampling and property determination, mining, mineral extraction and processing. This will cover areas vital for establishing manned lunar or planetary bases. The support will consist of consultation in areas of DOI/BOM expertise and of some testing to characterize the extraterrestrial material samples. DOI/BOM will also participate in the design and development of equipment or methods to be used in lunar or planetary environment for either sample collection or excavation including rock fragmentation, and mineral extraction and processing.

ARTICLE V -- FUNDING

A. Nothing in this Agreement shall be construed to imply any commitment of NASA/JSC's or DOI/BOM's funds or appropriations to each other. In addition, each party's resource commitment to this Agreement is subject to availability of appropriated funds.

B. For special requested projects or tasks involving the commitment of funds, the initiating party will process the appropriate procurement and funding document.

ARTICLE VI -- DURATION, MODIFICATION, AND TERMINATION

This Agreement shall become effective upon the last signature hereto, and will remain in effect for 3 years, or until such time as it is terminated upon 90 days' written notice of either party. However, upon mutual written agreement, said Agreement may be terminated at any time.

FOR: DEPARTMENT OF THE INTERIOR

Robert C. Horton
Robert C. Horton
Director
Bureau of Mines

Date Nov. 4, 1985

FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Robert C. Goetz
Robert C. Goetz
Acting Director
Lyndon B. Johnson Space Center

Date Feb. 3, 1986

United States Department of the Interior

BUREAU OF MINES
2401 E STREET, NW.
WASHINGTON, D.C. 20241

June 20, 1986

Mr. Jesse W. Moore
Director
Lyndon B. Johnson Space Center
Houston, Texas 77058

Dear Mr. Moore:

The research staffs of our organizations have established mutual research interests resulting in the signing of Interagency Agreement No. 14-09-007-1228. We, in the general area of space exploration and utilization, consider this as an extension of our previous cooperative research in the Apollo program. At that time, working with James J. Gangler from NASA Headquarters, the Bureau participated in the basic research on lunar resource utilization as a member of the Working Group on Extraterrestrial Resources. As early as 1962, this group was developing techniques for reducing the dependence of lunar and planetary exploration on terrestrial supplies. I am pleased to see that cooperation is being reestablished and see great potential for benefits for both our agencies.

The ratified Agreement requires that each agency designate a key person to act as liaison for this interagency cooperative effort. The liaison functions in the Bureau of Mines will be under the direction of the Deputy Director, David S. Brown.

The technical management aspects will be handled by the Assistant Director--Mining Research, Dr. David R. Forshey, and his staff in Washington, D.C. The lead Center for this research will be the Twin Cities Research Center (TCRC), Minneapolis, Minnesota, under the direction of the Research Director, Dr. Lewis V. Wade. The cooperative effort was initiated by Egons R. Podnieks, Senior Staff Scientist at TCRC, and he will continue to provide the coordination and liaison within the scope of the Agreement.

Sincerely,

[illegible]

Director

^3He on the Moon

Issues:

1. What is the range of measured ^3He concentrations?

2. How does ^3He abundance vary from place to place on the moon?

3. Why is ^3He correlated with titanium?

4. How does ^3He vary with depth in the lunar regolith and what is the depth of the lunar regolith containing significant ^3He?

5. How can we predict ^3He abundances in a lunar region without having samples?

6. Is it possible that regions of ancient regolith have higher ^3He concentrations?

7. Is it possible that some lunar process have concentrated ^3He in some regions or "ore bodies"?

8. Is it practical to mine enough ^3He to provide a significant product?

9. What are the power requirements of the mining system?

10. What is the weight of the mining system?

11. Should the mined material be sized before extraction?

12. Should the mined material be mineral concentrated or beneficiated?

13. What is the best way to liberate the ^3He?

14. What is the best way to collect and store the ^3He?

15. What is the power requirements of the system which extracts the ^3He?

16. How much does this system weigh?

17. What are the economics of the overall scheme?

18. What are the political and legal ramifications?