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LARGE-SCALE PROCESSING OF LUNAR MATERIALS; Krafft A. Ehricke, North American Space Operations, Rockwell International, El Segundo, California.

Large-scale processing of lunar materials is defined as quantity production and value addition (at least to the level of refinement, if not of semi-finished and finished products) on an industrial scale and mode of operation. Industrial developments have two major aspects: technological and socio-economical. Although the presentation concentrates on the technological aspects, socio-economical considerations represent a part of the rationale underlying the methods considered most promising and economically competitive for the large-scale processing of lunar materials.

The two fundamental premises used are those pointed out by the author at the 23rd International Astronautical Congress in 1972:

1. The large-scale exploitation of lunar raw materials can become attractive not because lunar abundances of industrially important elements exceed terrestrial ones (in fact, the opposite is the case), but because the biological nature of the terrestrial environment places more stringent constraints on the exploitation and associated acceptable technologies of exploitation of increasingly poor deposits than the lunar environment. In other words, the primary advantage of lunar industries appears to be that it offers the option of separating processing space and living space (production and consumption) rather than offering materials not or insufficiently available on Earth. This also implies that the lunar environment should, if and when economically viable, be used not only for primary industrial purposes (raw material extraction), but for value-adding (manufacturing) processes as well.

2. Large-scale use of space for manufacturing can unfold only in conjunction with lunar resources (although certain Earth resources must be added). Orbiting factories near Earth are restricted to special products, because large-scale refining (e.g., of bauxite to aluminum) or production of non-special semi-finished products does not offer hope of becoming economically competitive, even for the most energy-intensive processes, because of the energy required (and the thermal, if not other, waste released into the biologically relevant atmosphere) to transport the raw materials into space. The Moon offers a low-g vacuum environment on the surface and a relatively easily accessible zero-g environment in circumlunar orbit. Both environments can be used advantageously as processing space for

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secondary industries. In the case of the surface, this means that the lunar extractive industry should not degrade to a relevant extent the existing vacuum environment, least of all with a chemically aggressive gas such as oxygen, which is the main "waste product" of a lunar extractive industry. Because of the gravitational conditions in the Earth-Moon system, space manufactured quantity productions, based predominantly on lunar resources, can be provided to the terrestrial and extraterrestrial market at lower cost and lesser environmental burden than near-Earth orbital quantity productions (other than low-mass high-value products) based on terrestrial resources.

The first of the above points defines the reason for the potential attractiveness of large scale lunar processing; the second point stipulates the basic modes for maximum utilization not only of lunar resources, but of lunar environments as well and its potential economic superiority (except for special products) over large-scale terrestrial resource processing in near-Earth space.

In this frame of reference, the discussion covers the four principal sectors of large-scale lunar processing--methods of extraction and refining a manufactured products spectrum and products transportation. The primary energy source importantly affects the quantity capacity and the economics. The use of nuclear (non-steady) energy and solar energy are compared.

In the extractive sector, the choice also has a bearing on whether the extractive process is based on indigenous concentrations (IC method) or on prior concentration enhancement (CE method). The IC method can use solar or nuclear detonation energy. The CE method must use the latter. It is shown that nuclear detonation processing (NDP) is more economical, at least initially, but more likely on a permanent basis. The IC method can be carried out above ground or underground. In the latter case, the use of concentrated thermal energy from nuclear detonations is even more advantageous over the use of solar energy than for surface operations. The EC method must be carried out underground. In neither case, depths of more than 50 to 75 m appear necessary. Underground extraction is favored because it appears to be the only economic option to assure maximum protection of the lunar vacuum environment. It is realized that postulating the use of nuclear charges does not conform with the letter of the present nuclear test ban treaties, but it does not conflict with their spirit which is aimed at the prevention of hostile uses. If Man should move into space within a frozen plasma field of terrestrial distrust and antagonism (although space ventures are supposed to have the opposite purpose and effect) a rational modification of the ban of nuclear energy charges may not be attainable and large-scale extraction of lunar materials must be based on higher initial cost and on the IC method. In the Soviet Union, nuclear charges for canal construction projects to increase the water supply of the Caspian Sea have reportedly been tested successfully.

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The refinement of the enriched material will occur initially on the lunar surface (above or underground) but could also take place in part in circumlunar orbit after an economical transportation system, requiring a minimum of Earth-supplied fuel has been introduced. The electromagnetic accelerator, variously suggested during the past twenty years is particularly suited for quantity transportation from surface to orbit, since it is fully compatible with the preservation of lunar surface vacuum. The production of industrial liquids (at minimum supplies from Earth) and suitable methods of refinement are pointed out. Special attention is given to the processing and use of the large amounts of oxygen obtained as side products of the extractive industry.

Semi-finished and finished products involve a wide variety of products, including, for the terrestrial markets, large quantities of electronic components, high-temperature alloys for improved thermal conversion equipment, ultra-hard alloys, special bearing alloys for transportation systems, foam metals, special alloys for sea water resistant structures, and brine resistant geothermal power equipment, to name only a few of the initial product lines; for the extraterrestrial market, large structures for lunar and circumlunar factories and dwelling units, for large structures in geosynchronous and even in near-Earth orbit. It is shown that second generation lunar material processing can advance to the level of organic chemical industries which pose particular ecological burdens on Earth.

Central to the development of geosynchronous and terrestrial quantity markets and to the evolution of an organic chemical lunar industrial capability is a low-cost transportation system. It is shown that electromagnetic acceleration from the lunar surface beyond the circumlunar orbit to geosynchronous orbit or Earth is not the optimum solution. Two low-cost non-nuclear interorbital transportation systems achieving between 1300 and 4000 seconds terrestrial propellant specific impulse are described, which make the above development of large-scale processing and marketing of lunar materials possible.

Editors Note - For specific details and references see -

Ehricke, Krafft A. (1975) Space Industrial Productivity - new options for the future, (Presentation to subcommittee on Space Science and Applications 22-30 July 1975). North American Space Operations, Rockwell International, El Segundo, California.

DISCUSSION (Ehricke Paper)

SPEAKER: I was intrigued by your last slide. Could you explain what an orbitron is and an asteron.

EHRICKE: Yes, in addition to the electromagnetic accelerator on the ground I have a total electromagnetic system operating with an electromagnetic accelerator on the lunar surface and one in orbit. Now you see, since the length of the track is porportional to the square of the velocity, you are really better off if you have two delta V's rather than one very large delta V, in terms of overall mass. So I'm merely launching into lunar orbit. Then in lunar orbit, I'm launching out of lunar orbit, in this electrical scheme, with a similar lunar - accelerator. Now the term lunatron stems from Bill Asher from NASA, Huntsville, about 15 years ago or so, and I just adopted that term, and the orbitron is named similar to it. Now by launching a mass toward Earth on the orbitron, of course, you are changing the orbit, an elliptical orbit. You then slowly turn the accelerator around and now accelerate in opposite direction lunar supply materials or lunar rocks, which then restore your circularity again. Now this is a little bit involved. The chemical system initially seems to be simpler and have considerable advantages. The next two slides too show the orbitron under construction and the total system based - and the one thereafter, based on the electromagnetic system. Here is the orbitron, here is the lunar factory in its orbit, and here are the various ground phases of it, and here is the ground system. But I believe the chemical system utilizing - and if I may show one slide more please, utilizing the advantages of transporting the oxygen into near-Earth orbit in order to finance, so to say, the transport of hydrogen into the lunar orbit leads to specific impulses of the effective specific impulses of this order of magnitude. In other words, I'm using here a concept that is similar to the term fuel-specific impulse in air breathers. You know, where you get very large specific impulses simply because the oxygen is available free, so to say. Now the launch system that you saw there a moment ago, the oxygen-hydrogen runner, is actually recuperating the exhaust gasses again so that therefore the launching of oxygen into lunar orbit, even by chemical means, can be done with almost no contamination of buildup or gas release into the atmosphere and constant resue of the oxygen-hydrogen, then decompose again to water, burn again to oxygen-hydrogen, captured, chilled, redecomposed, and so forth. This gives you some very favorable economic conditions.

SPEAKER 2: Concerning the use of nuclear explosives, (on the Moon), I wonder if you would comment on two points. First of all, the existing structure of international treaties and their application to the utility of of nuclear explosions in this light; and secondly, the problem of radioactivity.

EHRICKE: Very briefly, first of all, the nuclear treaty merely is designed to be a weapon system ban. I think it can very easily be modified to allow peaceful nuclear detonations under controlled conditions. Number 2, the Russian's themselves are right now again planning and have actually tested nuclear detonations to build large channels to refill the water level in the Caspian Sea. That's going on on Earth here right now, so it's being done, so I don't think this is really much of a problem. The radioactivity is, on Earth, for a 5- to 10-kiloton bomb in the order of 3 months, low enough that you can go into the cavity. These are the experiences in Nome, Ranier, and some other underground detonations. So it's merely if you phase it right you would have to wait perhaps to wait 3 months to get into that particular cavity, but if you plan your cavities ahead, so to say, then you're getting to them when you can get into them. In addition to this, some of the nastier materials as far as radioactivity is concerned are less abundant on the Moon, especially in depth, for example, sodium and so forth which I think are more toward the surface. So as a result of which, I would expect that you probably could get even a little bit faster into the cavity. And thirdly, I'd like to deploy as few people as possible. People are very expensive, and as many machines as possible, so that the cavity - and the bringing out of the basic material into another cavity or into a higher level still underground would primarily be done by machines, so they're insensitive to some radioactivity.

SPEAKER 2: When you mentioned the particular nuclear species, the new type found there, I presume you're particularly referring to things like strontium and iodine which are indeed rare.

EHRICKE: That's correct.

SPEAKER 2: And that's a useful observation. When we're talking about the treaties, I have in mind particularly the outer space treaty which does forbid any nuclear explosion for any purpose.

EHRICKE: Yes, I'm aware of that, but I do think that the reason for it is weapons. It is not actually a peaceful application. Once a peaceful application becomes clearly apparent, can be controlled, I do believe that underground detonations on the Moon could be permitted.