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TRASH ON THE MOON: THE INEVITABLE CONTAMINATION OF THE LUNAR ENVIRONMENT

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INTRODUCTION

All human societies share a common trait: the production of waste, which increases in variety and volume as the society matures. As we move out into space to colonize other worlds, man will take this talent for waste with him. Indeed, we already have begun this process on the Moon. The United States alone has left over 18,140 Kg. of hardware on the lunar surface through various exploratory sorties, beginning in the early 1960's (Cortright, 1975).

Permanent colonization of the Moon will produce three basic types of surface waste: organic, atmospheric and manufactured. While lunar waste encompasses a broad range of orbital and surface sources (see figure 1), this study will concentrate on the handling and disposal of manufactured waste, commonly referred to as 'trash'. Lunar trash production will vary from a mere environmental eyesore to an environmental hazard in the form of spent nuclear power sources (see figure 2). Management of this trash must become a coordinated effort for all nations establishing a permanent presence on the Moon to assure the preservation of the natural state of this body and prevent unnecessary risks to explorers in the near and distant future.

SOURCES OF TRASH

Sources of lunar trash are best defined through colony activities, of which, three major categories can be defined: personal activities, colony base activities and transportation activities (see figure 3). Colony maturity will control the production rate of each of these categories in two ways. First, by the level of activity done during a particular phase (and therefore the number of crew members and equipment present), and secondly, by the origination point of the various materials, equipment and expendibles. The young colony will be a research outpost dependent on Earth for 100% of hardware and resupply. The mature colony, however, will be capable of local production of some supplies and products.

BASE CONSTRUCTION

Establishment of the lunar base will be a hardware intensive phase of operation, requiring at least ten landers with associated payloads of modules, equipment, power sources and expendables, totalling 199,580 Kg. of deliverables at the start of mining operations (Briggs, et.al. 1985). This will leave approximately 48,378 Kg. of landers strewn about the colony site, along with another 4,535 Kg. of construction debris. This startling amount of scrap material will accumulate during the first five years of colony activity (see figure 4).

PERSONAL ACTIVITIES

The average American produces between 2.2 and 2.7 Kg of garbage a day, including foods scraps; up from 1.8 Kg. a day at the **turn** of the century (Marro, 1987). A number of factors peculiar to life on the Moon will drop this daily production rate significantly: (1) the separation of food scraps from trash (which account for 8.1% of the average American figure) will be required on the Moon due to the 'active organic' classification of food products. This classification identifies sources of bacteria producing compounds, which will be processed with other human waste products for recycling; (2) the scarcity of materials combined with the expense of transportation to the lunar surface; (3) paper, a major component of American trash, estimated at 37% of the daily rate, will be present in much smaller quantities on the Moon and in some forms, absent altogether (i.e. newspapers, periodicals and junk mail).

Factoring out these items, the average production rate in early lunar colony life should be closer to .90 Kg. per day, per colonist. At this rate a permanent crew of twelve will produce just over 3,628 Kg. of personal trash a year. These rates are expected to increase as the colony increases in size and sophistication, particularly when mining operations begin. As mining and eventually manufacturing capabilities develop, a number of items once brought from Earth will begin to be produced on the Moon. Increased availability will provide easier replacement, which will make discarding these items easier. It is estimated that trash production will increase to 1.5 Kg. per day per colonist. At this rate a 100 member colony will produce approximately 49,885 kg. per year.

Not included in these personal rates are the by-products from wet-oxidation processing of human waste. The average crew member will produce a combination of carbon ash and phosphate salts totalling 7.71 Kg. per year. For a crew of twelve this represents an annual amount of 92.98 Kg. of compounds rare to the lunar environment. It is likely that these materials will be stored for later addition to the lunar regolith in preparation for farming.

COLONY ACTIVITIES

Trash items produced by general colony activities will include cloth, plastic, ceramics, glass, aluminum, steel, and various rare metals (Dalton,et.al. 1972), plus a number of potential hazadous materials. Chemicals generated by processing equipment, experiments and life support equipment will require a method of collection, handling and disposal. The more unstable of these items will need special storage to avoid exposure to the thermal extremes of the lunar surface.

Colony activities will also be responsible for producing what will possibly be the most serious problem confronting the trash management coordinator: disposal of exhausted nuclear power sources. The SP-100 reactor currently under study by NASA, and the prime choice for a non-solar power source, has an expected lifetime of approximately seven years (Buden,et.al. 1985). Currently favored by designers is the use of lunar regolith in conjunction with this reactor to provide necessary shielding, whether by placement in a nearby crater (French,1985), or by the construction of a shadow shield (Bloomfield,1988). The radio - active power source, as well as the environment within a five kilometer radius will become off-limits for many years into the future. Only two alternatives exist for handling these spent reactors: refurbishment or diposal by direct burial. With colony expansion, it is conceivable to have the unacceptable situation where tens of these units are scattered across the lunar surface, creating 'dead-zones' around the colony.

With lifetimes of seven years, it may appear a little early to concern initial explorers with the disposal of these power sources. However, the chance of an early shutdown due to general failure or impact damage is a possibility that must be planned for. It would be prudent to install even a minimal infrastructure at the power site to handle eventual disposal operations, prior to the area becoming radioactive.

SURFACE EQUIPMENT

Though lacking an atmosphere to support the weathering conditions imposed on terrestrial equipment, the extremes of the lunar environment will prove demanding on surface equipment in other ways. Thermal cycling, the ever-present dust that plagued the Apollo astronauts and a high radiation flux will limit the useable lifetimes of components in these machines. Even sheltered and partially sheltered equipment will produce a variety of damaged parts, filters, supply containers, etc., at a given rate based on expected lifetimes. Excluding nuclear power sources, the operations and maintenance of a 12 member colony will produce 3,628 Kg. of trash per year.

TRANSPORTATION ACTIVITIES

Cislunar transportation between low Earth orbit (LEO) and the Moon will involve a variety of expendable and partially - expendable vehicles at various stages in the development of the colony. Until mining facilities are operational and liquid oxygen (LOX) is available on the Moon, the predominant vehicle for transporting base elements will be the expendable lander.

Initial cislunar transportation will involve little more than placing hardware on the lunar surface to construct the base, which will leave only a 4900 Kg. lander behind each time as trash. Manned landings and departures will add additional equipment and supplies at landing sites. At four resupply missions a year using expendable descent stages, 9,070 Kg. of additional trash will be generated, 85% of which is lander weight.

Surface transportation activities encompass the movement of personnel and cargo from the landing sites to the colony, or to remote scientific locations beyond the colony perimeter. In general, these activities will utilize first generation designs for transport and construction equipment, with the true tests done in-situ. At present, the maintenance and replacement schedules for these machines are too difficult to predict. One certanty that is known however, is threat faced by surface equipment from radiation (Adams, et.al. 1985). By altering the structure of electronic circuitry, damage can vary from simple replacement to worse case scenarios of component failure leading to loss of control and catastrophic failure of the machine. It is estimated that surface activities will produce 3,174 Kg. of trash per year prior to mining activities. Figure 4 depicts estimated trash production for the first five years of manned presence on the Moon.

DISPOSAL TECHNIQUES: A DISCUSSION

Conservative calculations show that for a crew of twelve occupying the colony for a full year, traash generated will approach just over 20,000 Kg. excluding lander weights and mining operations. Reduction of this trash through the use of shredders and solar furnaces will help to minimize volumes, but will still leave an appreciable amount of material to be dealt with. In developing an effective lunar trash management program, five factors must be considered: the process must be energy efficient; the required equipment be simple and ideally, already used in the colony's operation; disposal should have minimal impact on the environment; radiation exposure to colonists is kept at a minimum; and the method is economical from a terrestrial and lunar point of view.

When basic human survival in in question however, little time is spent on protecting the very environment threatening man, as witnessed by the ring of garbage encircling early Antarctic bases and the tainting of water-producing snow with diesel engine exhaust (Lewis,1965). During establishment of the initial lunar outpost the practical approach to trash disposal may well be the use of a nearby crater. This crater-filling cannot continue,however, once the outpost facilities are operational. As threats to survival lessen, a system of trash management must be quickly instituted.

RECOMMENDATIONS

INITIAL PROCEDURES

Since the trash quantities generated by the early research outpost phase of the colony will be low,this trash could, if necessary, be handled through surface storage until burial operations became feasible. Containerization of the reduced trash would be preferred using a standard container, which would facilitate eventual handling and disposal by robotic or man-tended vehicles.

LANDERS/CONSTRUCTION DEBRIS

An aggressive approach will be required for landers and the debris left by base establishment operations. Unlike the benign, low-volume trash of crew and base operations, this category encompasses large weights and volumes, as well as potential hazards from umspent fuel remaining in the landers.

Lacking a permanent landing facility, the expendable landers will touch down at various locationsnear the colony site. Collection of these vehicles to a common point will be essential and easily completed with the crane/transport system used to unload the habitat modules. Storage of the landers in a work tent will prevent exposure to the temperature extremes of the day/night cycles and provide a well-illuminated shelter to allow crew members to dismantle or modify landers and warehouse parts. Components of landers, such as engines, pressure vessels and valving may find secondary uses in facility augmentation. Other landers might be outfitted to serve as remote 'safe-houses' along exploration routes, or be segmented for experiment pallets.

Construction debris will include an assortment of storage cannisters, heat shielding and shipping dunnage, aside from various discarded parts taken from construction equipment. As with the landers, much of this debris may find secondary uses around the colony.

NUCLEAR POWER SOURCES

Discarded power sources, such as the SP-100 pose a severe problem for the lunar trash management program. Of the two alternatives of refurbishment or burial, burial is likely to be the preferred method for this style of power source. An alternative to direct burial and a method of grouping these sources together, is the creation of a subsurface chamber as studied by Ehricke (Ekricke,1985). In this study, a one kiloton nuclear blast produces a 40 meter diameter cavern. A cavern half this size would suffice for reactor disposal of a growing colony, long past the seven year turnover cycle.

Added benefits include centralization of active and spent power sources which will reduce environmental contamination and allow a single group of robotic servicers care for the power sources and handle the disposal. Site preparation, whether in a crater or using a shadow shield would be limited to a single site instead of several (see figure 5). Further study is required to analyze the effects imparted to sub-surface structures by a cavern producing blast, and verify the technical feasibility of boring or melting an access shaft of sufficient diameter to allow the reactor to fall into the underground chamber.

CONCLUSIONS

While it is true that America is entering the twilight of landfill disposal for solid waste, this method has served this industrialized nation well for decades (Marro, 1987). Direct burial of reduced non-recyclable trash will be the only feasible long-term solution on the lunar surface as well. The pivotal question of course, is when should the procedure begin? The machines used on the Moon to bury habitat modules could provide small-scale landfill operations, though from a practicle point of view, this may not be feasible until mining operations have begun.

A potential delaying factor is cost. Maintaining a permanent presence in remote environmnets is always expensive, and costs involved in space exploration are extreme by terrestrial comparisons. For a lunar colony these costs include new technology development for machinery (Crockford 1988; Brazel, et.al. 1988), transportation to the lunar surface (Sauer, 1985), added labor hours and the risks to crew health due to increased radiation exposure on the lunar surface.

A second potential delaying factor involves this radiation environment. Lacking appropriate robotic vehicles in the early colony we must ask ourselves, is the maintenance of the lunar environment in a near pristine state worth the additional exposure. For each stage of colony growth, mission planners must monitor trash production and determine at what point will the accumulation of debris begin to affect the safety and efficiency of the colony.

A MANAGEMENT PLAN

With the size of the colony in a constant state of change for the first five years, the management plan must be flexible. With landfill as the ultimate goal for a disposal solution, the early management plan must set conditions early to better meet this goal as the infrastructure matures (see figure 6).

Effective collection procedures will be required as early outpost assembly nears completion and the research base becomes operational. Compaction and shredding (Singer,et.al.,1973) of appropriate trash will help to keep volume down and ease storage of the debris in containers. Colonists must determine the proper locations for temporary storage of this containerized trash, considering travel distances as well as close proximity to future mining sites.

The placement of nuclear power sources will require a substantial effort on the part of the crew in the early colony, the degree of difficulty tied to the choice of a regolith shielding system ultimately used. It is doubtful that the centralization of power sources discussed earlier will be within the technical capabilities of the early colony. This would force the existence of at least one power source that would have to be disposed of in the near future.

The colony's existence on the surface of a planetary body, in itself establishes a certain protocol for dealing with trash. Unlike their orbital counterparts, surface colonists will not have to worry about volume restrictions or orbital debris; when the garbagge can gets full, they can empty outside! It will require insightful planning effort to develope a flexible management plan that establishes trash as a problem to be dealt with, and dealt with from the beginning. A problem that will require expenditures of time, money and machinery, as well as crew discipline, to protect the lunar surface from ourselves.

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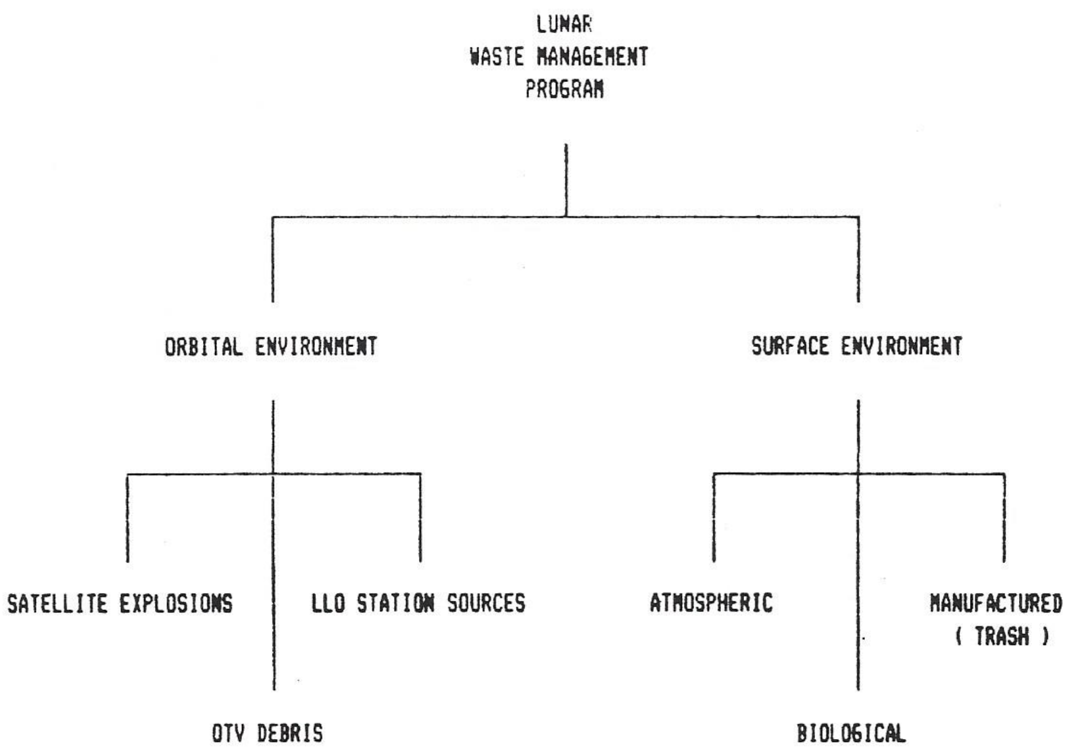

Figure 1. Lunar Waste Management Program

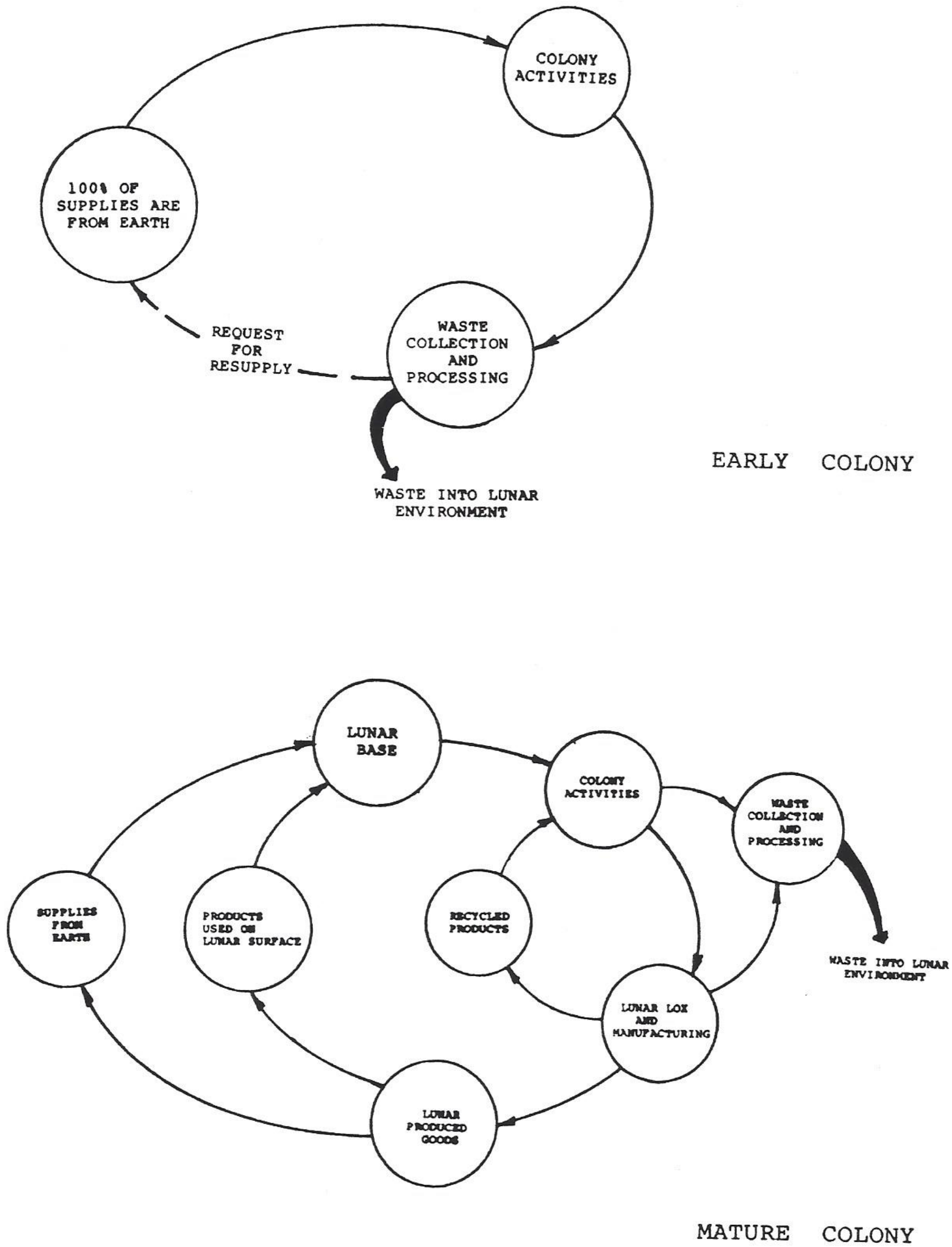

Figure 2. The Lunar Trash Cycle

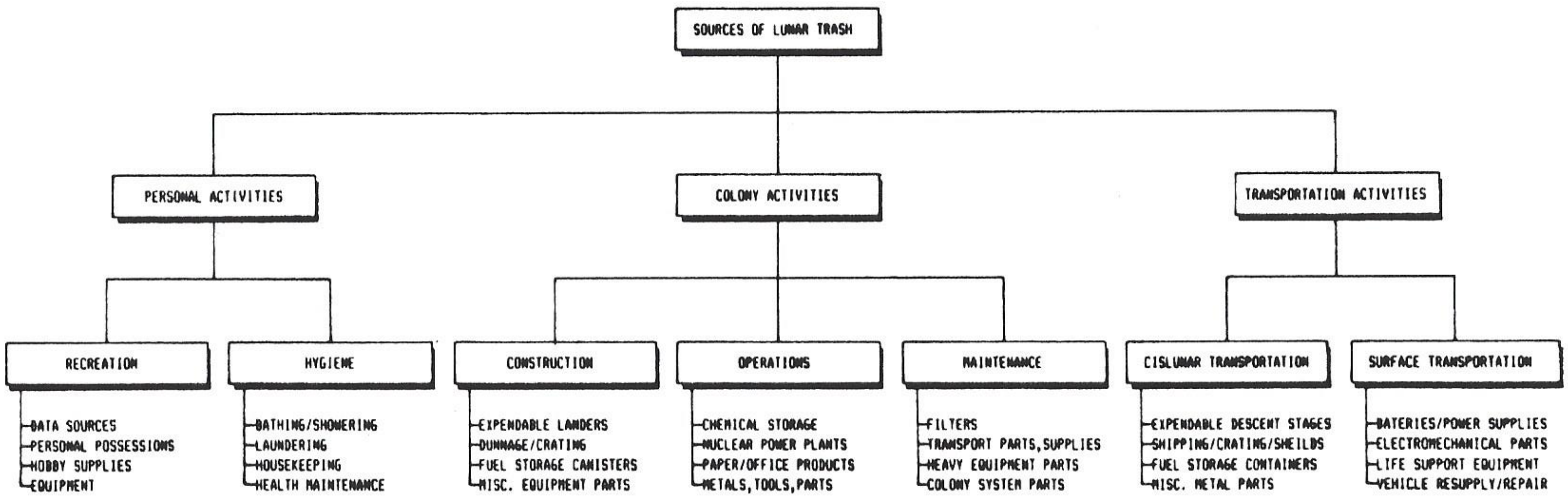

Figure 3. Sources Of Lunar Trash

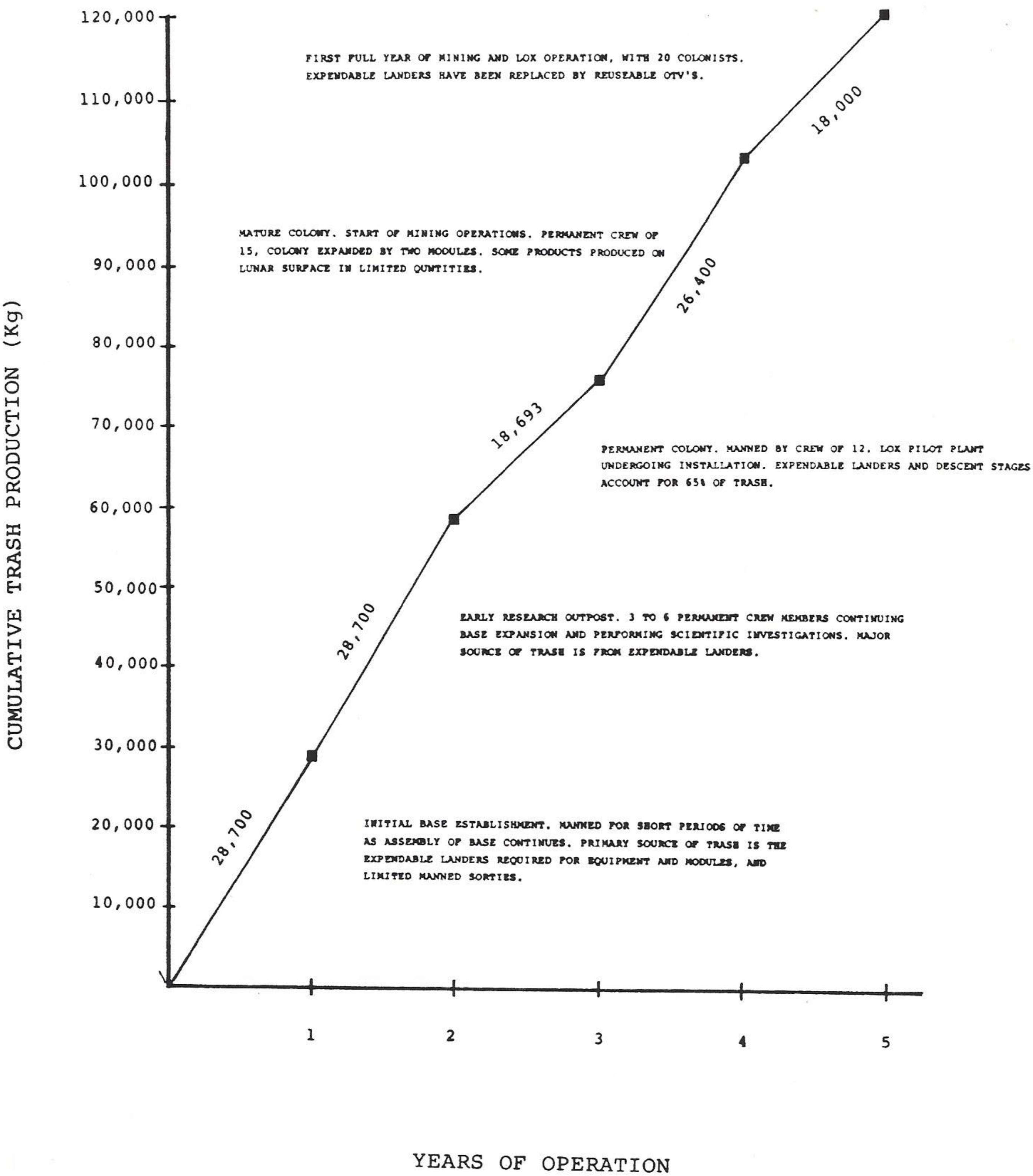

Figure 4. Trash Production Rates vs. Colony Maturity

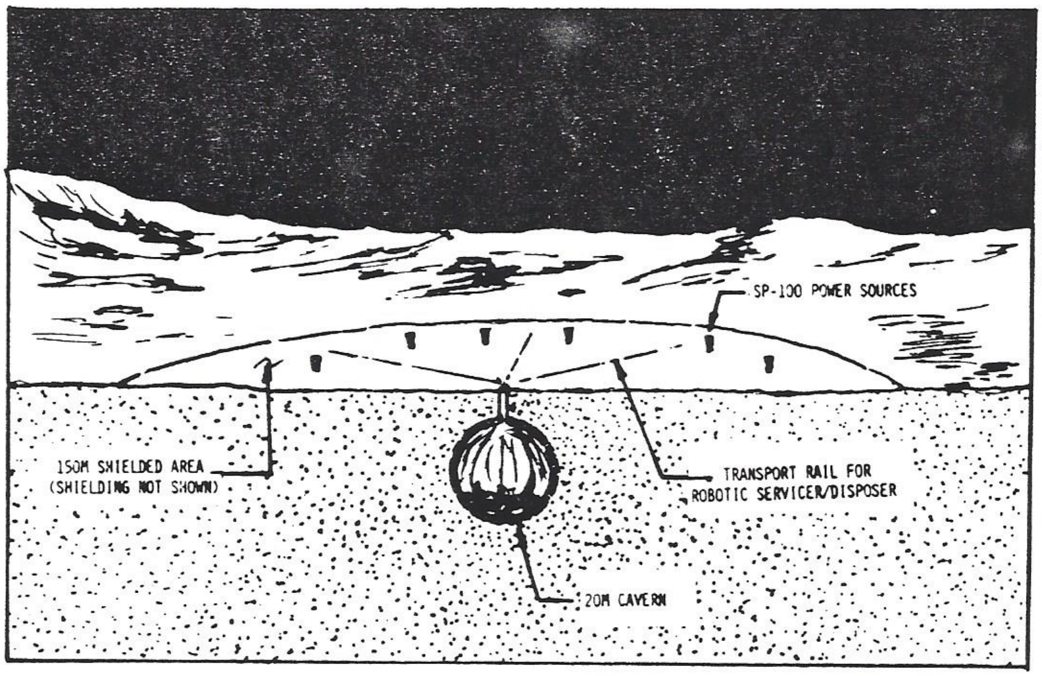

Figure 5. Subsurface Disposal of Nuclear Power Sources

COLONY SIZE	COLONY ACTIVITIES	MANAGEMENT METHOD
Initial Research base	. Construction of base . Scientific experiments	. Surface storage . Landers left at original sites
Early colony (6 permanent crew members)	. Continuing base expansion . Scientific experiments . Installation of LOX pilot plant . Installation of nuclear power source	. Begin landfill operations on a small scale . Collection and processing of expendable landers
Mature colony (50+ colonists)	. Start of mining operation . Start of LOX production . Expanded scientific research . Tourism begins	. Full scale landfill operations . Comprehensive plan for power source disposal . Trash management expanded to handle remote outposts . Matured recycling technology in place

Figure 6. Trash Management Plan vs. Colony Maturity