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A Moon Programme: The European View

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A Moon Programme: The Next Step?

Today, the need for long-term and ambitious programmes is more important than ever. Large programmes are necessary to stimulate global economic development, not this time through technology 'outbursts' of the type induced by the World Wars of the 20th Century, but through purely peaceful, civilian initiatives that would give a new meaning to the word 'work' and would provide a means of occupying everyone's talents for the common good and to the benefit of future civilisation, namely our children.

Space programmes represent one such initiative, one that encompasses science and high-technology activities on a planetary scale, serving mankind, helping it to communicate, and offering a 'mirror' with which to survey our home planet, whilst at the same time exploring the Universe and its eventual habitability

Currently, the major space nations are directly involved in or associated with the development of an international space station, which is today's largest international space programme The next international space programmes will see the continuation of space science, Earth observation and space applications, leading eventually to the exploration and exploitation of the Moon, and to the setting up of manned outposts first on the Moon, and later on Mars, sometime during the 21st Century. The Moon therefore constitutes a logical next step

It is important that Europe continues to play an important and rewarding role in such future programmes and it is well equipped to do so. Over the years, Europe has developed the critical space capabilities needed for lunar missions: these include the Ariane-5 launch vehicle, lander engines, sophisticated communications systems, sensors, etc. Europe also has a large pool of talented scientists, engineers and industrialists who have a strong interest in studying and using the Moon.

It is therefore arguable that, particularly now, Europe has the opportunity to take an initiative towards an International Moon Programme By taking that first step, Europe can maintain a certain autonomy and independence and can thereby also develop itself into a more attractive partner for future cooperative endeavours.

The Benefits

An enterprising Moon Programme can serve to accelerate the successes of European space activities in many sectors. It would represent a long-term investment in a high-technology international programme that would tax the skills and ingenuity of the scientific and industrial participants, pushing them to the frontiers of knowledge and know-how, leading to new discoveries and innovations, new and better products, and improvements in industrial processes and methodologies. The end result would be greater competitiveness and the creation of new markets, new jobs, and new sources of income.

The benefits from the proposed Moon Programme stem from the fact that:

- it involves many of the same technological and industrial domains as advanced military programmes; it is a suitable and peaceful alternative for maintaining and further developing Europe's expertise in the fields of electronics, computers, instrumentation, communications, materials, propulsion, energy management, etc.;
- it stands at the crossroads of science and technology, which it would push to their limits. Scientific aims are the strongest incentives; the harsh environment of space, together with the extreme performance requirements on spacecraft and their launchers, pushes both the technology and the work organisation and management methods used in its development, to the limit. This is profitable not only for the main aerospace contractors, but also for the sub-contracting companies, where the assimilation of space-activity knowhow is a strong factor in enhancing their competitiveness;
- it represents a strong motivation for future generations, and acts as a powerful driver for the development of high-tech education, as young people foresee a future in the corresponding fields of activity. This motivation is profitable to industry in general;
- it fosters, but also benefits from, international cooperation through the spreading of knowledge and the diffusion of technologies, leading to economies of scale and to a more rapid spread of innovative applications.

A Moon Programme should not just provide a set of sophisticated tools to benefit a small specialist elite. The Moon is already part of our 'environment' and should be accessible to all, not just those privileged to be chosen as astronauts.

Via the sophistication of tele-presence and virtual reality, the Moon Programme proposed here can 'involve' everybody on Earth, whatever their chosen technical profession. It would be an incentive for the younger generations to come to develop their best talents in exploiting this new and as-yet virgin territory.

The approach proposed here would ensure that the Programme would be affordable, and also that Europe would accrue all of the above-mentioned benefits. There are four aspects to the underlying philosophy: the Programme is founded on a set of long-term objectives and the principle of a phased approach; it would contribute substantially to the advancement of scientific knowledge and make use of the most advanced technologies; it would involve and motivate scientists and technologists active in many disciplines, exploiting such advanced communications capabilities as tele-presence and virtual reality; and it would be conceived in a manner that would preserve the lunar environment.

Why the Moon?

The Moon is a natural laboratory of 38 million km^2, a 'history book' of the evolution of the Solar System and of the Sun itself, and a large and very stable platform from which to conduct astronomical and Earth-oriented observations. In addition, its soil is an immense reservoir of natural resources, which could prove essential to the future expansion of space activities in general, as well as being of benefit to mankind back on Earth.

As the Earth's largest, closest and most easily reachable neighbour in space, the Moon would make an ideal staging-post for man's future exploration of the Solar System, and a valuable test bed for the development of the necessary skills and technologies. The Moon can serve as:

- A *laboratory* for geological, geophysical and geochemical research ('Science of the Moon') and for life-sciences research ('Science on the Moon').

  Many important questions about the history and the geology of the Moon still remain unanswered. The first challenge in the context of life-sciences research and the ecology of the Moon is to establish an artificial ecosystem on a celestial body other than the Earth for the first time.

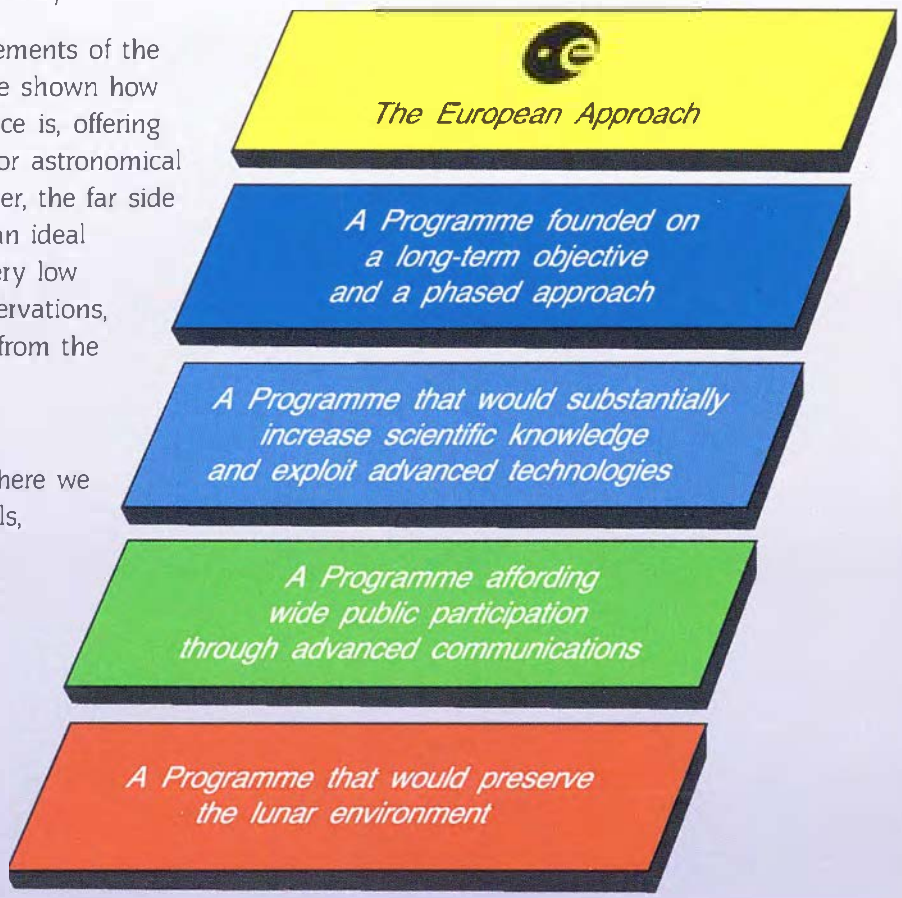
  The spin-offs to be expected from this venture vis-a-vis our terrestrial existence would include a better understanding of the dynamic processes regulating the Earth's own ecosystem. The maintenance and propagation of life with a different gravity level and in the presence of increased radiation can be regarded as fundamental scientific research in its own right.

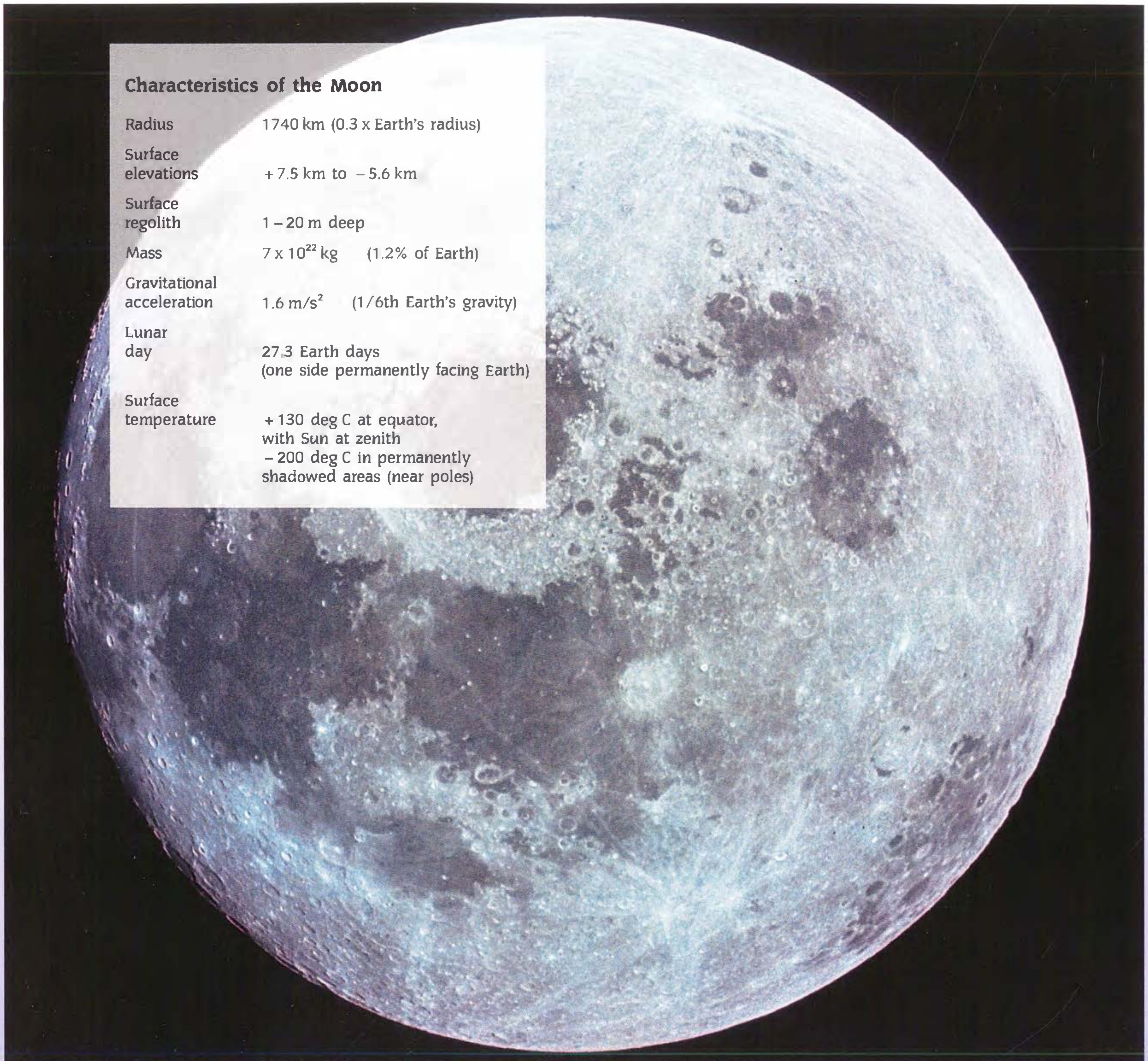
- A *platform* for astronomy, with its unlimited access to electromagnetic and particle-radiation spectra ('Science from the Moon').

  The seismic measurements of the Apollo missions have shown how calm the lunar surface is, offering a very stable base for astronomical instruments. Moreover, the far side of the Moon offers an ideal observing site for very low frequency radio observations, being well shielded from the Earth's strong radio emissions.

- The *closest place* where we can develop the skills, capabilities and technologies needed for man's future exploration of the Solar System.

  Many systems and technologies developed for the Moon might be directly applicable for Mars missions, particularly the ability to use robots to prepare for later human visits. 'Living off the land' on the Moon by exploiting its resources would provide valuable experience as well as a more realistic basis for sending astronauts to Mars at a later date.

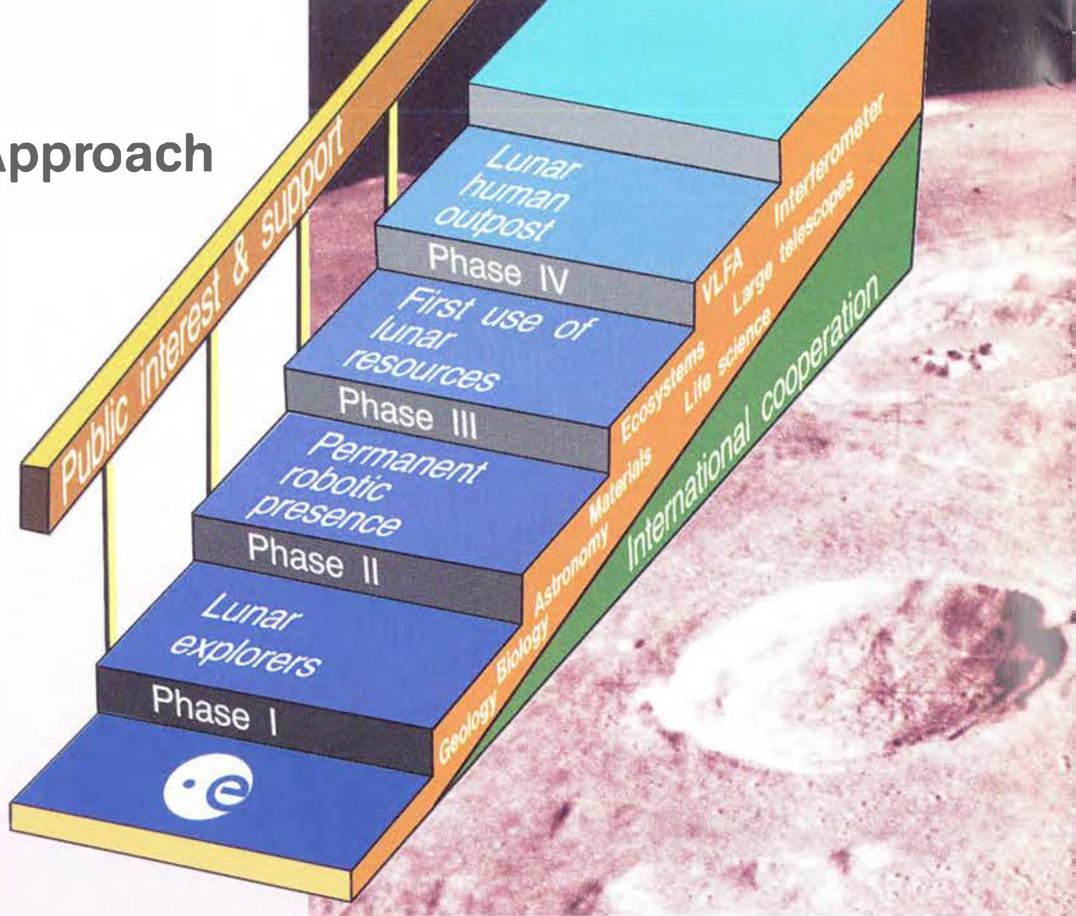




Characteristics of the Moon

Radius	1740 km (0.3 x Earth's radius)
Surface elevations	+7.5 km to −5.6 km
Surface regolith	1 – 20 m deep
Mass	7×10^{22} kg (1.2% of Earth)
Gravitational acceleration	1.6 m/s^2 (1/6th Earth's gravity)
Lunar day	27.3 Earth days (one side permanently facing Earth)
Surface temperature	+130 deg C at equator, with Sun at zenith −200 deg C in permanently shadowed areas (near poles)

Europe's Proposed Phased Approach



The approach being pursued for a possible International Moon Programme is one attempting to reconcile long-term vision and short-term constraints, far-away objectives and quick achievements, scientific requirements and political, economic, educational and technological goals, whilst at the same time preserving the lunar environment.

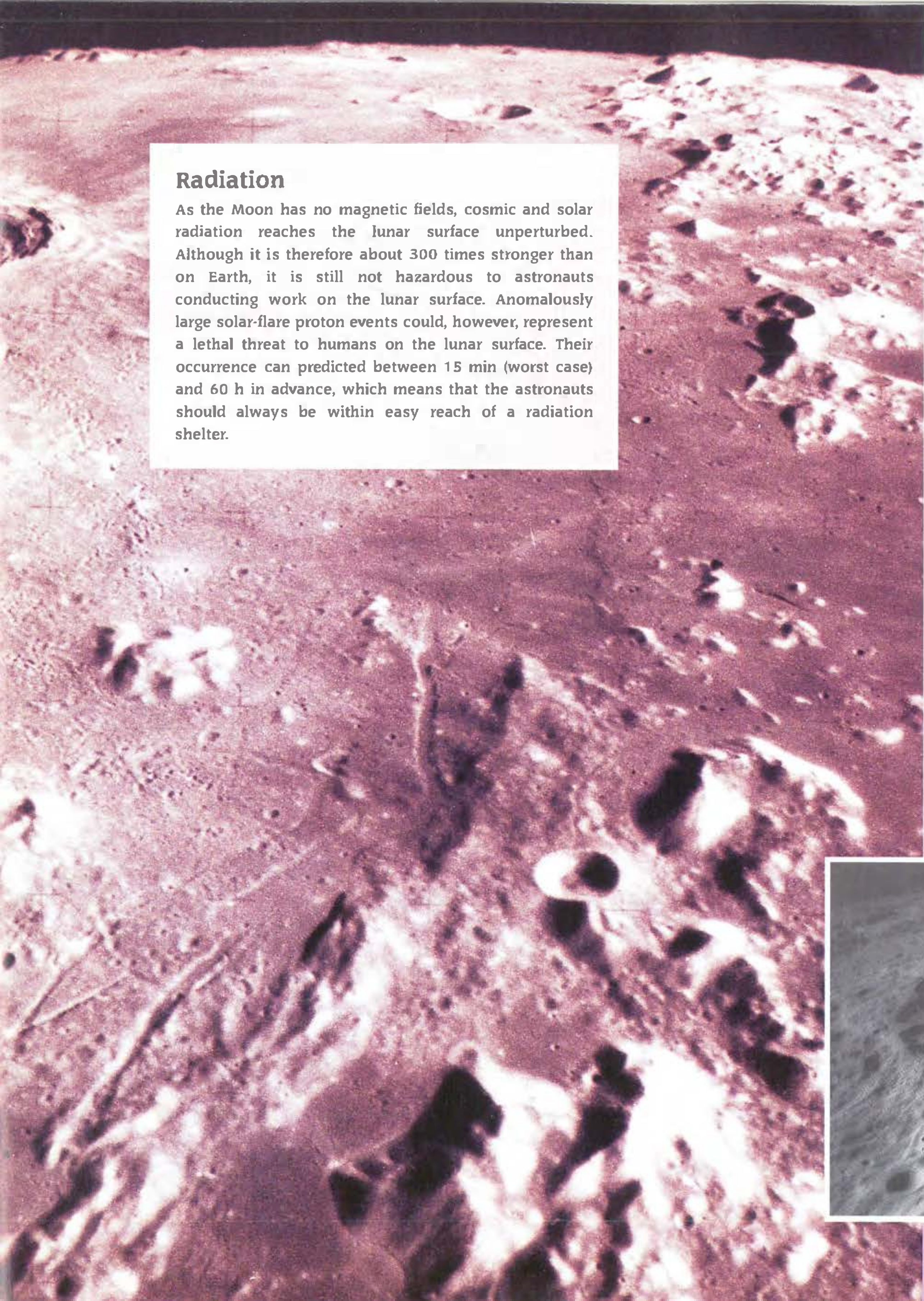
To be viable, the programme must build on existing expertise and the lessons that have been learnt from the past thirty years of space activities. The implementation must be progressive and compliant with the available financing, starting with small, low-cost, automatic missions and progressing to more complex robotic endeavours, and eventually to manned missions.

The **first phase** would be built around **lunar explorers**: orbiters, landers, rovers. Its goal would be to improve our overall knowledge of our natural satellite by making an inventory of lunar resources and acquiring a full and detailed knowledge of the lunar surface, and also to demonstrate key technologies for the next phases.

The **second phase** would see a **permanent robotic presence** on the Moon. By then, a detailed knowledge of the lunar environmment and its characteristics would have been acquired and more complex instruments could be installed on the Moon (e.g. radio-astronomical or seismological instruments). Extensive use of tele-presence and tele-operation techniques would facilitate more complex interactive operations of the sort required for geological surveying.

Dust

Most of the Moon's surface is covered with a 3 – 20 m thick blanket of soil, consisting of a mixture of dust, known as 'regolith', and scattered boulders, which range from just a few centimetres to some 200 m across. About 35% of the regolith is made up of particles less than 50 microns in diameter (largely magnetic glass). The soil cohesion is high due to the prevailing vacuum, but the soil particles also adhere strongly to material surfaces for the same reason. Sensitive components and mechanisms must therefore be carefully protected against lunar dust.



Radiation

As the Moon has no magnetic fields, cosmic and solar radiation reaches the lunar surface unperturbed. Although it is therefore about 300 times stronger than on Earth, it is still not hazardous to astronauts conducting work on the lunar surface. Anomalously large solar-flare proton events could, however, represent a lethal threat to humans on the lunar surface. Their occurrence can predicted between 15 min (worst case) and 60 h in advance, which means that the astronauts should always be within easy reach of a radiation shelter.

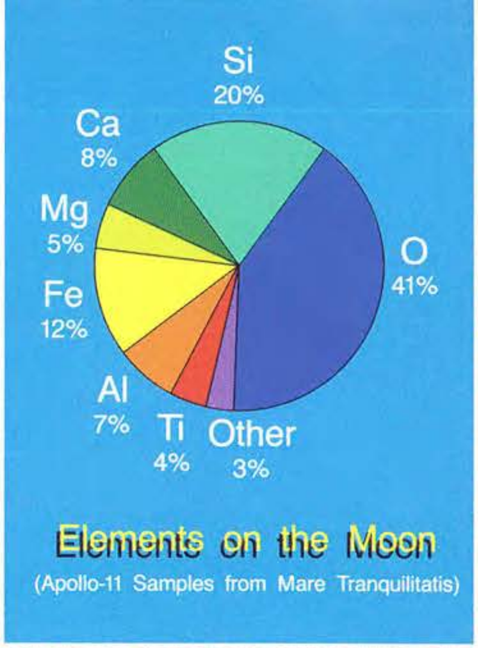
The **third phase** would focus on the **first exploitation of the lunar resources and environment**. Techniques for oxygen production and construction by using on-site materials would be investigated and large astronomical instruments could be deployed. Further significant life-science experimentation would be facilitated by installing dedicated bio-laboratories.

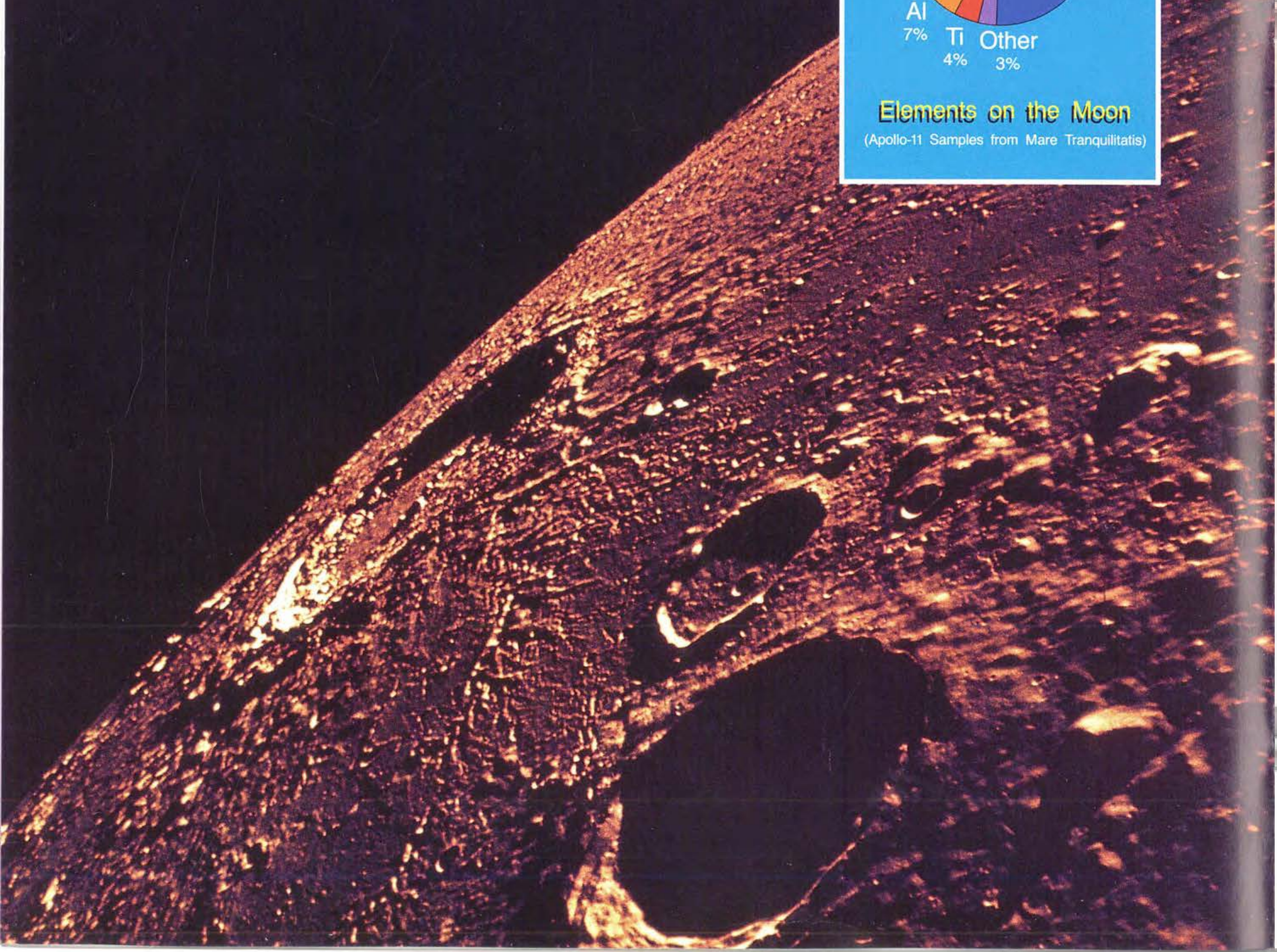
The **fourth phase** would see the installation of the **first 'human outpost'** on the Moon. Extended stays by humans on the Moon imply the building up of a base and systems supporting autonomous life there, such as oxygen production, life-support and environmental control systems.

Europe can build on its available means and expertise to embark on the first phase autonomously, after which growing international cooperation will stimulate the subsequent phases.

The Moon Programme and its Science

The Lunar Science Advisory Group, set up by ESA, has identified the scientific interest of the Moon, addressing specifically the benefits of **'Science of, on and from the Moon'.**





Science of the Moon

The Moon has preserved its primordial crust and is the most easily accessible location in the Solar System for studying the evolution of a natural planet immediately following accretion. It therefore holds the key to our understanding the early evolution of the Solar System. It also constitutes a natural laboratory in which general geological processes can be studied and understood.

Following the Apollo and Luna programmes, and more recently the Clementine project, our general knowledge and understanding of the Moon has improved dramatically. However, a number of major scientific themes have still to be investigated in greater depth, including:

- The origin of the Earth – Moon System.
- The thermal evolution and internal structure of the Moon, as well as its geochemistry.
- The impact-cratering history of the Moon and the nature of the impact processes themselves.
- The formation of the regolith.
- The evolution of our Sun, through studying the record encapsulated in the lunar soil.

Science on the Moon

The establishment of a lunar base would provide life scientists with challenging projects in the fields of exobiology, radiation biology, ecology and eventually also, with a manned presence, human physiology.

In exobiology, studies on the Moon would contribute to our understanding of the principles leading to the origin, evolution and distribution of life. A laboratory on the Moon would allow the analysis of a wide variety of lunar samples, and perhaps also meteoritic material in pristine condition.

The Moon also provides a unique laboratory for radiation-biology studies, with builtin sources of both electromagnetic and ionising radiation, in which to investigate the biological importance of the various components of cosmic and solar radiation.

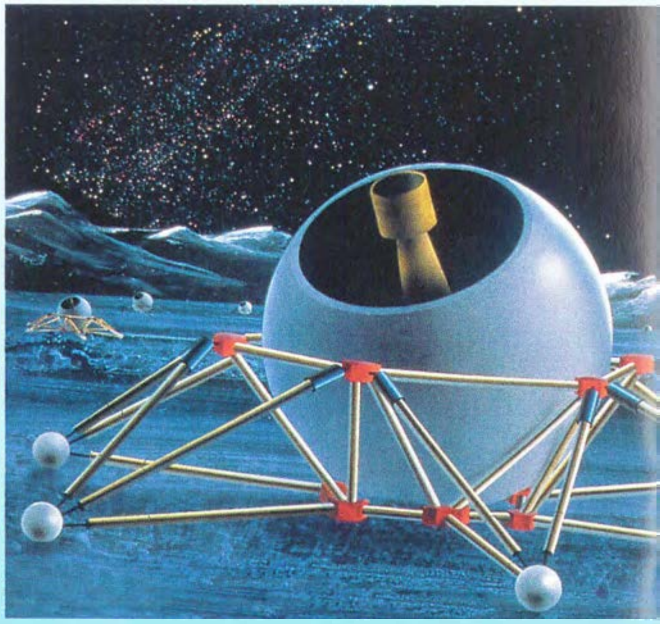
In preparing for the establishment of a human outpost on the Moon in the years to come, radiation monitoring, shielding, and solar-flare shelters must be studied, together with a reliable life-support system including bio-generation systems, as well as a health-monitoring system.

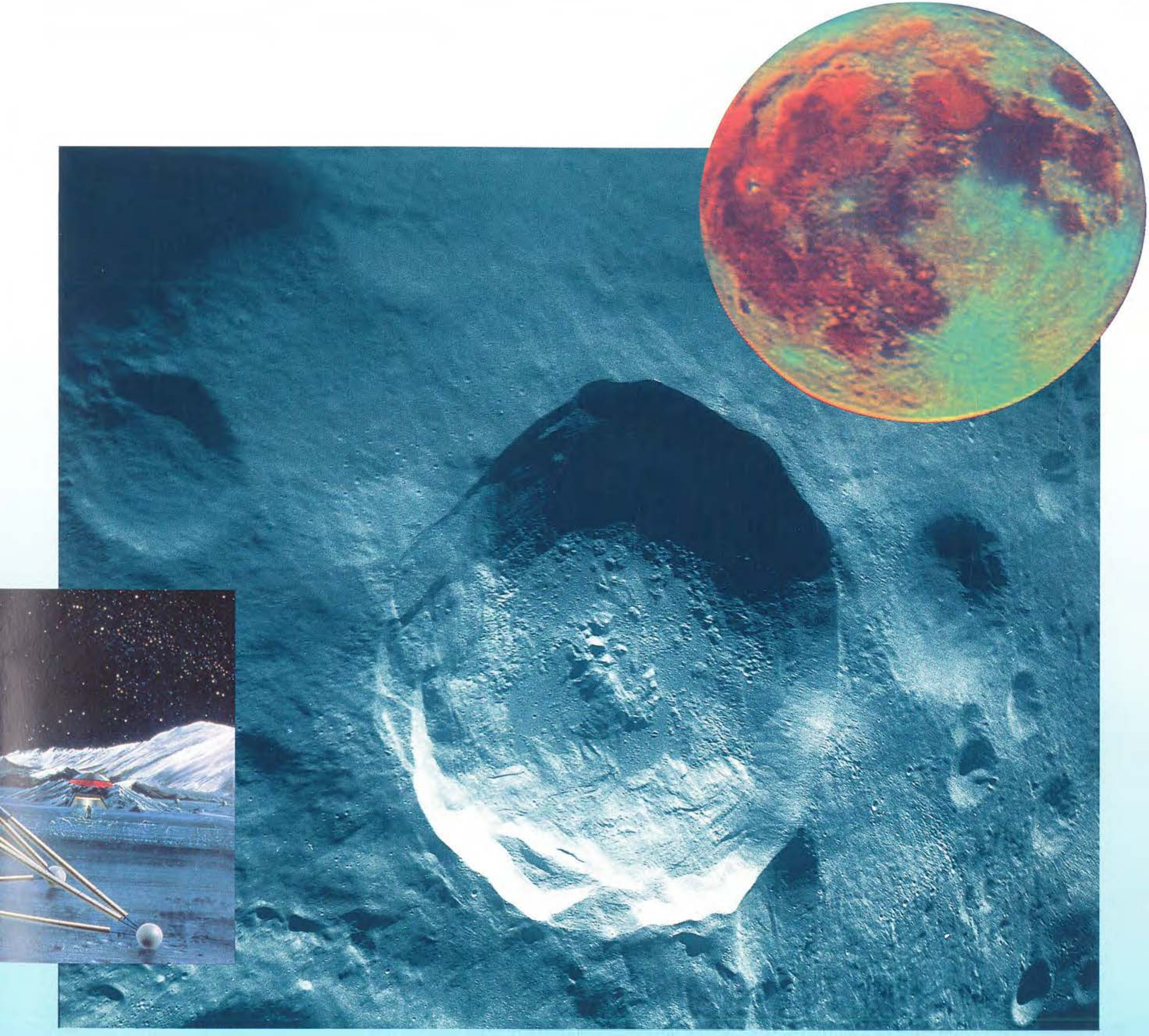
Science from the Moon

The Moon is generally considered to be a unique astronomical site, offering better observing conditions than on Earth and with the unique advantage of affording access to the entire electromagnetic, particle and cosmic-ray spectrum.

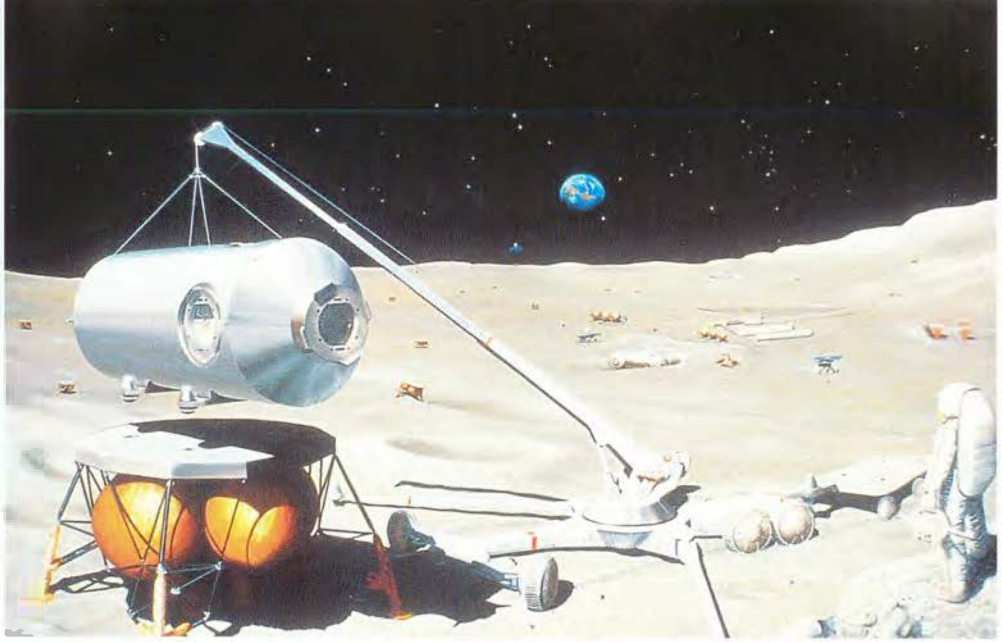
The Moon is a large, stable and slowly rotating space platform, whose position and orientation are known exactly at all times. No thruster units are needed for 'positioning' or 'station-keeping', and instrument pointing is as simple as back on Earth. The far side of the Moon is the only place in the inner Solar System with a naturally 'clean' electromagnetic environment. One could also shield sensitive equipment from damaging radiation using the regolith material, and exploit the shadowed surface inside craters near the Moon's poles for the siting of passively cooled instruments.

The next step in astronomy will be the search for higher angular resolution, for the imaging of stars, galaxies and quasars, binary systems, and ultimately of extra-solar planets. This will eventually necessitate the construction of large antennas, telescopes, and interferometric systems on the Moon. Very low-frequency (VLF) observations and interferometry in the ultraviolet to submillimetre spectral range will open new windows on the Universe, impacting on almost every field of astronomy. Although the Moon is not the only place in space where such observations are possible, kilometric sized (and larger) arrays and very large telescopes will most probably need to be sited on the lunar surface.





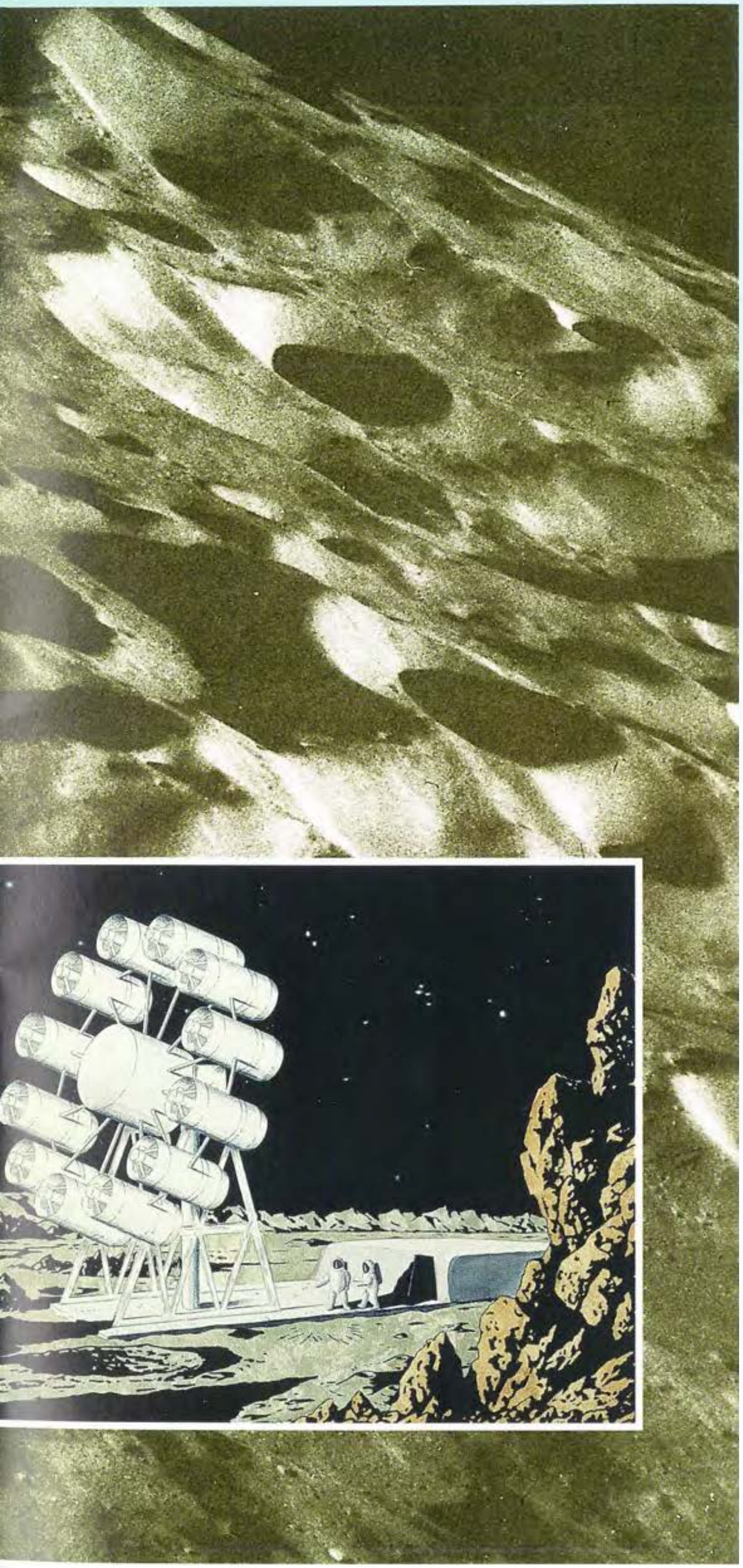
The Moon Programme and its Technology



The Moon Programme that Europe is proposing is based on a fourphased approach that involves fundamental challenges in terms of both technology and mission development.

The eventual goal of the fourth phase of the Moon Programme is the realisation of a human lunar outpost. Many technologies are required for closed-environment and life-support systems to cope with the harsh environment, its radiation and large thermal range, to recover local resources, and to provide sufficient power and reliable communications, as well as safe human transportation. Also, a synergy between robotic tele presence and man-tended operations is required. All of these technologies need to be initiated at a timely moment during the earlier phases. The scientific utilisation also needs to be synchronised with the progress in the technical capabilities, such as the development of remotely operated laboratories, geological surveying and the tele-construction of astronomical instruments.

During phase three, the local environment would be utilised to support the exploration activities. This requires the development of new methodologies for mining and extracting such elements as oxygen, aluminium, iron and titanium. Exploitation of lunar oxygen (which constitutes 40% of the Moon's soil) can substantially reduce the launch requirements for round-trip lunar missions. Various metals and glasses can be used as raw materials for the construction of large telescopes, for cosmic-ray protection, and eventually for building a lunar base. The success of this phase depends strongly on the maturity of Moon-wide expedition capabilities in terms of tele-presence supported by advanced robotics, high-data-rate communication, and tele-control and sensor technology, which need to developed in the preceding phases.



In the second phase of 'permanent robotic presence', robotic skills applicable using virtual-reality-type control need to be developed, as well as reliable high-rate data communication. Various sites on the Moon need to be readily accessible using efficient and accurate landers, for which throttlable engines and advanced guidance, navigation and control are required. Energy sources and mobility constitute major technology challenges for this phase. Micro-electronics and -mechanics would allow the sizes and masses of both the systems and payloads to be shrunk dramatically, thereby allowing more ambitious missions within the constraints of launch capabilities and budgets. By exploiting the capabilities of a robotic presence, scientific use of the far side of the Moon (e.g. for very-low-frequency arrays) and the permanently shaded craters at its poles (e.g. for infrared telescopes) can be developed in this phase, and geological expeditions can be conducted.

The first 'lunar explorers' phase is one in which the emphasis is on 'getting started', building up the knowledge and operational experience necessary for the later lunar-mission phases, using existing technologies and capabilities for the most part.

Although Europe has no direct lunar-mission experience, it possesses many relevant technologies that provide the possibilty of a quick start and of becoming a knowledgeable partner for the subsequent phases. For example, most of the systems that would be required for propulsion, power, communications, etc. are available in Europe. Several advanced sensor technologies for scientific observation and exploration are already being studied for the Polo, Rosetta and Moro projects. Special transmitters and digital transponders are being developed for the Huygens/Cassini mission. On the power front, highly efficient chemical batteries are available and regenerative fuel cells are currently being developed by ESA. A tele-operated robotic arm has already been flown on the Spacelab-D2 mission, while the thin-film technology developed for the XMM project could lead to efficient telescopes for lunar-surface operation.

The Role of Ariane-5

In its present configuration, Ariane-5 can deliver both lunar orbiters and lunar landers. Two of the possibilities for early lunar missions are dedicated Ariane-5 launches and 50:50 shared launches.

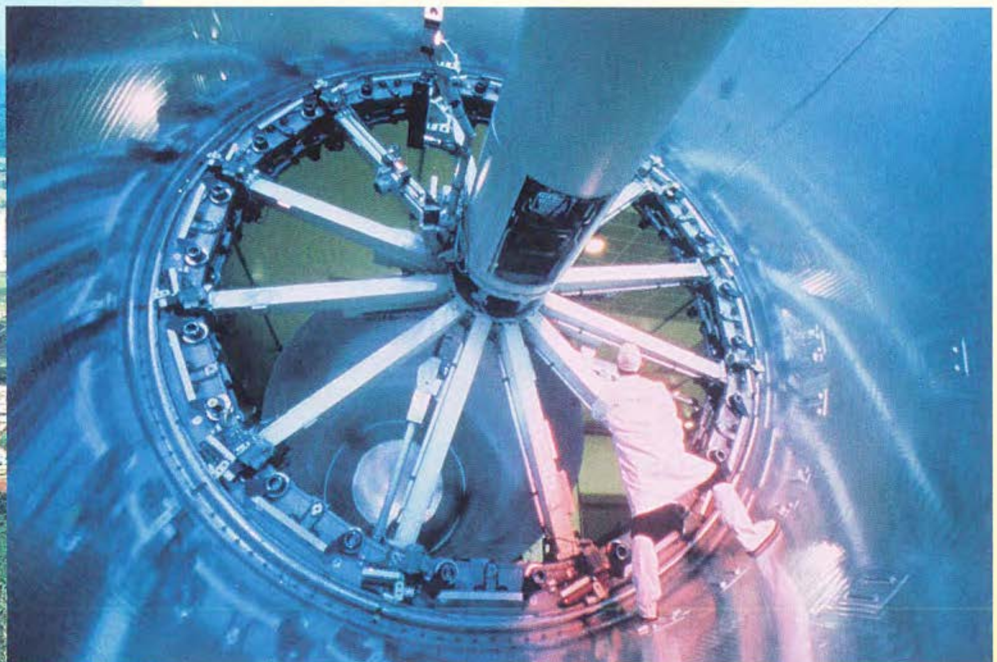
A dedicated Ariane-5 launch can put about 4450 kg of payload into a Lunar Transfer Orbit (LTO) and the timing of the launch can be optimised for that particular mission. The optimisation gains are comparatively small, however, so that practically speaking a dedicated lunar launch can take place at any time of year The transfer time to a low lunar orbit would be about 5 days, but this could be reduced to 2 days with a relatively modest fuel supplement of 140 kg. For a mission involving a lander, some 800 kg of payload could be landed softly on the Moon's surface.

The second possibility is a shared launch into Geostationary Transfer Orbit (GTO), but there are several operational constraints Customers for GTO orbits generally have a specific requirement in terms of the direction of the Sun at orbit apogee, which dictates a specific launch time each day. The plane of the Moon does not necessarily coincide with this Sun direction. In practice, the velocity increment required for lunar transfer from GTO is a minimum for just two launch windows per year, with extra fuel needed for other launch dates The transfer time would also be much longer, ranging from 40 to 60 days, depending on the position of the Moon at launch. For a 50:50 shared launch, 2870 kg of payload would be available in GTO, which can still support a significant lunar mission, such as a 400 kg orbiter combined with a lander carrying a 200 kg payload.

Ariane-5 can fully support the proposed 'first phase'. The transportation requirements for the 'second and third phases' can also be met using an upgraded version of Ariane-5. For the 'fourth phase', a new class of launcher with an even greater lift capability would probably need to be developed.

In lunar orbit, the visibility periods for communicating with Earth, as well as the eclipse periods (affecting power supply and thermal conditions) and the lighting conditions on the lunar surface below the satellite, depend on the particular type of orbit selected: polar, equatorial, etc.

Near-equatorial landing sites can be reached every two hours from a near-equatorial lunar orbit. Similarly, near-polar landing sites can be reached every two hours from a near-polar orbit. High-latitude (but not polar) landing sites, however, can be reached only from an orbit having an inclination at least equal to the latitude of the landing site. In this case, landing opportunities occur only twice per lunar month. In addition, landing sites behind the Moon would require a communications relay satellite.



Getting Started

It is crucial that the European approach to lunar exploration be pragmatic and realistic, emphasising near-term goals and achievements in the context of a phased approach. The European approach in the short-term could be centred around the initiation of an 'International Lunar Quinquennium' (2000 – 2005) that would focus worldwide attention on the Moon by offering a framework for international cooperation.

Europe could take the initiative by commencing work on the 'Lunar European Demonstration Approach (LEDA)'. The main goal of this mission would be to demonstrate key technologies essential to the success of the early phases of a new Moon Programme. A complementary scientific package would be added to the LEDA mission once the mission concept was chosen. This demonstration mission could be launched close to the turn of the century, relying on a shared Ariane-5 launch to keep costs low. Concepts being considered include a mission with a robotic payload as a lunar lander.

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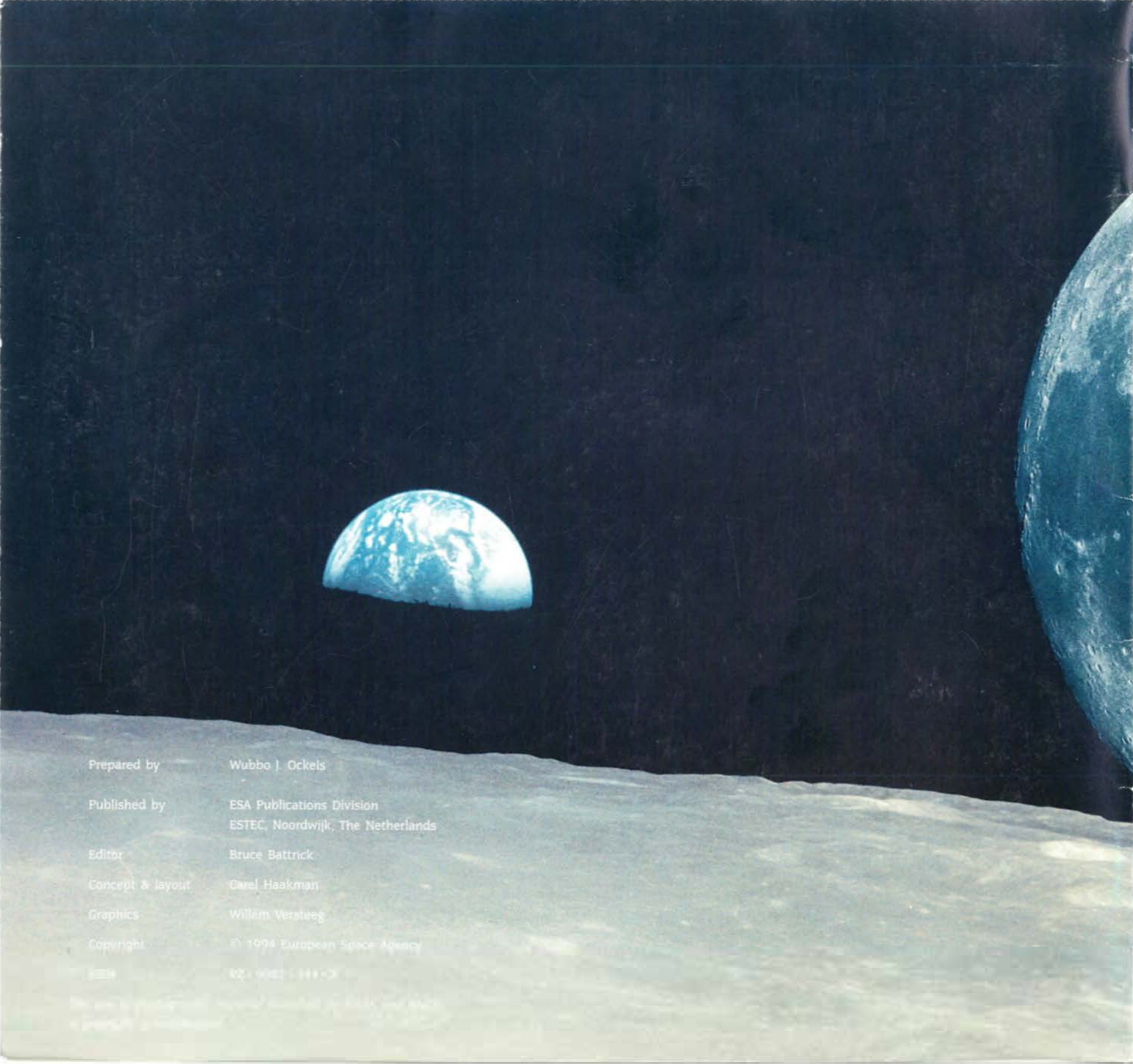

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