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NASA's SPACE PROCESSING PROGRAM

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ABSTRACT

The primary goal of NASA's Space Processing Program is to initiate utilization of space flight capabilities for economically beneficial activities in all branches of materials science and technology.

It is expected that the condition of virtual weightlessness obtained in space flight will permit unprecedentedly precise control over many known processes and development of many novel processes to manipulate and prepare biological materials intended for use on the ground. This expectation has already been verified in the case of electrophoretic separation of living cells through a sequence of experiments performed on the Apollo, Skylab, and Apollo-Soyuz Test Project (ASTP) missions. It is believed that further applications will be found as well, and that future reductions in the costs of space operations will make a large increase in the scope of space experimentation possible.

Plans are now being made for payload equipment to implement materials processing experiments on the missions of the Space Transportation System (STS). This equipment is intended to support a diversified program of NASA-sponsored materials processing experiments by all classes of scientists, as well as pilot activities by non-NASA sponsors. It appears feasible to organize payload systems that can implement a wide variety of activities without undue constraints from spacecraft resources, and on this basis we expect that STS payloads can begin to provide supporting services for research and applications more or less routinely fairly early in the 1980's.

The NASA Space Processing Program is conducted by the Office of Applications to develop uses of space flight that will support research efforts and manufacturing operations on the ground by processing materials in space. It is expected that the unique conditions that are available in space will provide a basis for a wide variety of economically beneficial services to science and industry in fields such as metallurgy, electronic materials, glass technology, fluid physics and chemistry, and in biological material preparation as well.

The primary advantage that such applications will seek to exploit is the condition of virtual weightlessness obtained in a freely moving spacecraft during unpowered flight. In low Earth orbit, which has been the usual setting for materials processing experiments in space, the gravitational field intensity is only a little less than it is on the Earth's surface. However, in unpowered flight a spacecraft and everything in it are freely accelerated by the force of gravity, and these accelerations are all equal with an accuracy of the order of one part in ten million. Therefore, gravity effects cannot produce appreciable relative velocities between objects in the spacecraft. For example, a lump of lead that was released very carefully so as to avoid imparting any impulse to it would typically drift a meter or so from its original station and then return during the orbital period of approximately 90 minutes, because its orbit would differ slightly from that of the spacecraft unless the two bodies' centers of mass happened to coincide. The forces needed to hold the lump of lead in a constant position relative to the interior of the spacecraft would be very small, and in fact they could be provided easily by air currents, acoustic radiation pressure, or electromagnetic interactions.

In liquid media the relative velocities that can be produced by gravity effects are much smaller, because the very small forces that are involved have to act against viscous drag forces that are typically a hundred times as great as those found in gases. For all practical purposes, therefore, the driving forces for thermal convection, sedimentation and other buoyancy effects are completely removed from liquid systems in space. This is a factor of considerable significance for chemical and biological procedures, because it becomes possible to work with heterogeneous chemical systems under experimental conditions where the only heat and mass transport effects to be considered are heat conduction and chemical diffusion. Since both of these effects are precisely calculable according to a relatively simple mathematical theory, it should be possible to apply extremely precise techniques of control and measurement to experiments with such systems in space.

The effects of weightlessness have been exploited to study a variety of processes in solidification, crystal growth, fluid physics, and physical separation methods in space flight experiments conducted over the past five years. Flights that have carried space processing experiments are indicated in the top section of the schedule chart shown in Figure 1. They include the Apollo 14, 16 and 17 lunar missions, the four flights of the Skylab program, and last year's Apollo-Soyuz Test Project (ASTP) mission. These flights have carried a combined total of 41 experiments and demonstrations related to materials processing.

In order to continue experimentation through the rest of the 1970's, the Space Processing Program has undertaken a series of rocket missions that will carry payloads on ballistic flights that each afford between five and ten minutes of experiment time. This project is called the Space Processing Applications Rocket (SPAR) project, and it is planned to conduct three flights per year until the project is superseded by experiment operations using the Space Shuttle and Spacelab. The first SPAR flight was carried out on December 11, 1975. It carried nine experiments, thus bringing the total for the whole program to 50; the distribution of experiments and demonstrations among the missions flown to date is given in Table I.

Five of the program's experiments have been directed toward developing new methods for biological preparations. In these experiments, electrophoretic separations have been performed in aqueous media that were stabilized against convection by weightlessness rather than by porous supports or laminar flow, and protracted separation runs have been accomplished on particles that would have sedimented very rapidly on Earth. These early experiments have mainly served to establish the technology needed for more advanced work in the future, but their results indicate that further development can be expected to result in refined and powerful separation methods that should be capable of quantitatively predictable results.

As the second section of Figure 1 indicates, the development (Phase C/D) of the Space Shuttle was initiated at about the time of the Apollo 16 flight, and the Preliminary Design Review (PDR) was held shortly after the ASTP mission. The first Shuttle Orbiter is scheduled to be rolled out toward the end of this year and will be flight tested within the atmosphere during 1977. Thus the design phase of the Shuttle project has been going forward concurrently with the experiments that NASA has been performing to verify the promise of materials processing in space.

During the design work on the Shuttle, the Space Processing Program has performed substantially continuous studies of potential modes of Shuttle and Spacelab utilization. However, it has been necessary to wait until the experiment results from the manned missions of the 1970's were available and the Shuttle design was substantially complete before embarking on final definition of Space Processing Applications (SPA) payloads for the Shuttle missions.

Phase I/II payload definition studies are now in progress and a competitive procurement will be held in the latter part of 1976 for payload design and development work which will begin in the first quarter of 1977. The development of specific equipment items will be phased to provide for deliveries at the approximate points shown in the third section of Figure 1, comprising two initial payloads compatible with the test flights of the Shuttle and two payloads for operational flights with the Spacelab in 1981.

In defining payload equipment for the Space Shuttle and Spacelab we have followed approaches intended to give experimenters easy access to space and maximize the scientific output of their experiment while minimizing the costs of operating them in space. Typical payload configurations that have been derived to implement this design philosophy are illustrated in Figure 2. In general space processing payload systems will be built up of modular, reusable equipment taken from a standard inventory of apparatus and supporting equipment, so that each item of equipment can serve many investigators and little apparatus will need to be developed specifically for individual experiments. The usual mode of operation will be to fly space processing payloads on missions shared with other disciplines, and the modular nature of the equipment will make it possible to take advantage of a wide variety of shared mission opportunities because each payload will only need to include the equipment necessary to its mission.

Payloads will also be organized for maximum productivity, so that the unit costs of processing material samples will be minimized. The system is being designed to that all of the equipment in a given payload can be operated during all of the time it spends in space. Since this concept requires many experiments to operate at once, the space processing equipment inventory will include an Auxiliary Payload Power System (APPS) that provides power from Shuttle type fuel cells and has a radiator to dispose of the resulting heat. The system will be capable of supplying 15 kw of electric power, and it is expected to free space processing experiment operations substantially from constraints due to limitations on the resources of the Shuttle.

Investment and operating cost questions are critical for materials processing in space because one of NASA's goals is to introduce activity sponsored by other government and private sponsors into space. This will be possible only if the costs of performing space experiments are within the range that such sponsors are accustomed to pay for research. The results of the Space Processing Program's current payload definition studies indicate that this may be achieved if the number of investigators served on each mission is large enough, and therefore the program is planning for payloads that will be capable of processing literally hundreds of samples for a diversified community of users on every flight.

This type of operation is unprecedented in space experimentation, and it will obviously provide flight opportunities for larger than usual numbers of investigators. Initially these investigators will perform their experiments un er NASA's sponsorship to develop experimental methods and demonstrate that space flight provides capabilities for fresh approaches and new discoveries in their fields. The Space Processing Program is employing a variety of means to engage the interests of qualified experimenters and define worthwhile applications; among these means are meetings such as the present one, working group activities in support of the payload planning effort, and participation in the SPAR project. In the early years of space processing experiments on the Shuttle and Spacelab, we expect of the order of 100 investigators to conduct research projects that use space activities to achieve their objectives. Among these will be projects dealing with the feasibility of biological and biomedical applications of space flight, some of which may be based on ideas brought out by this Colloquium. Assuming that these projects are as fruitful and inexpensive as planned, we believe that the investigators will soon find other sponsors wishing to support their work as well. If this is the case, then by the late 1980's we can expect to find that space experiments will have become a more or less routine resource in the kinds of biological and other work for which they offer substantial advantages.

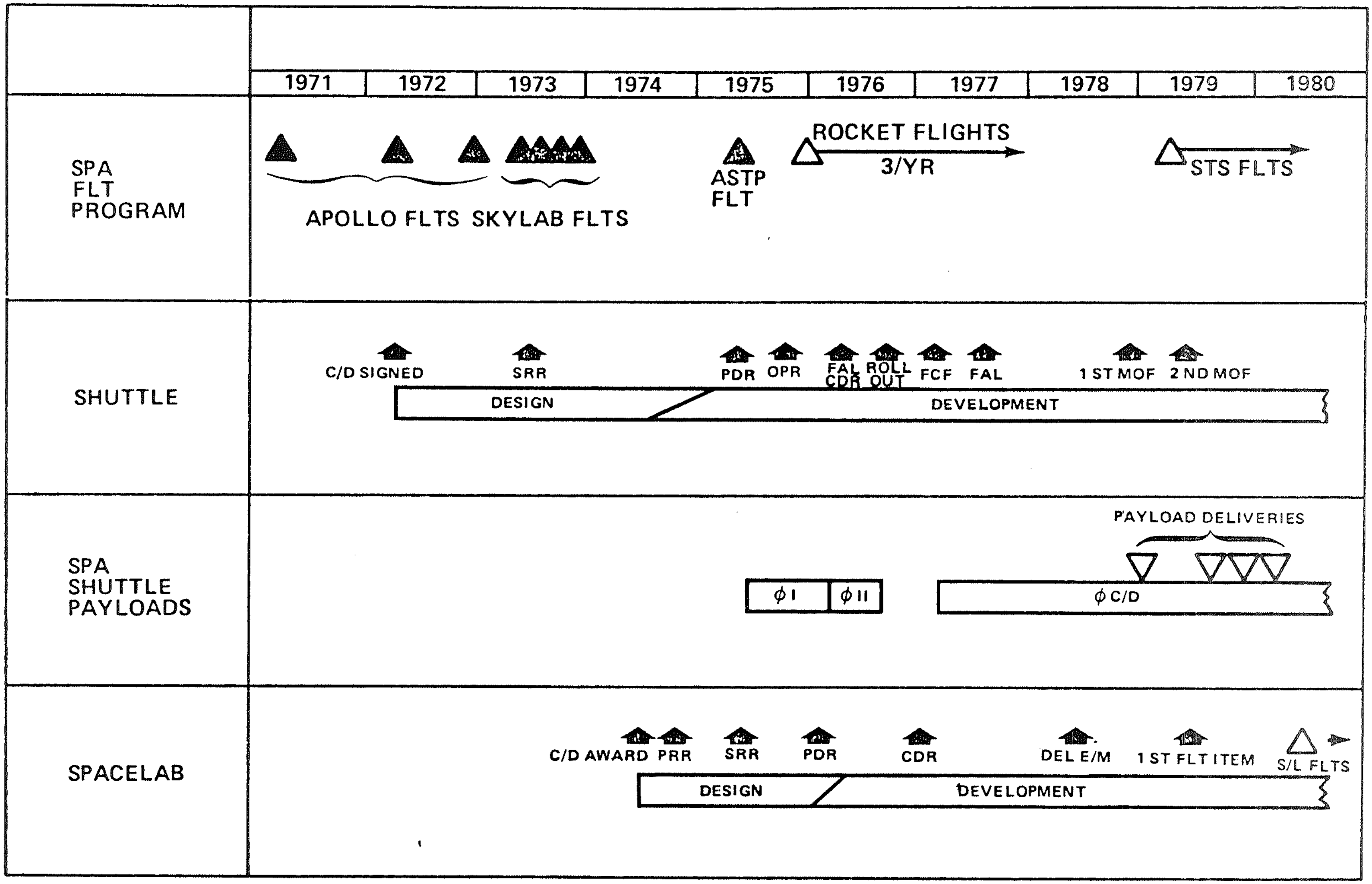

Figure 1.- Overview schedules for Space Transportation System, Space Processing Applications, and Spacelab.

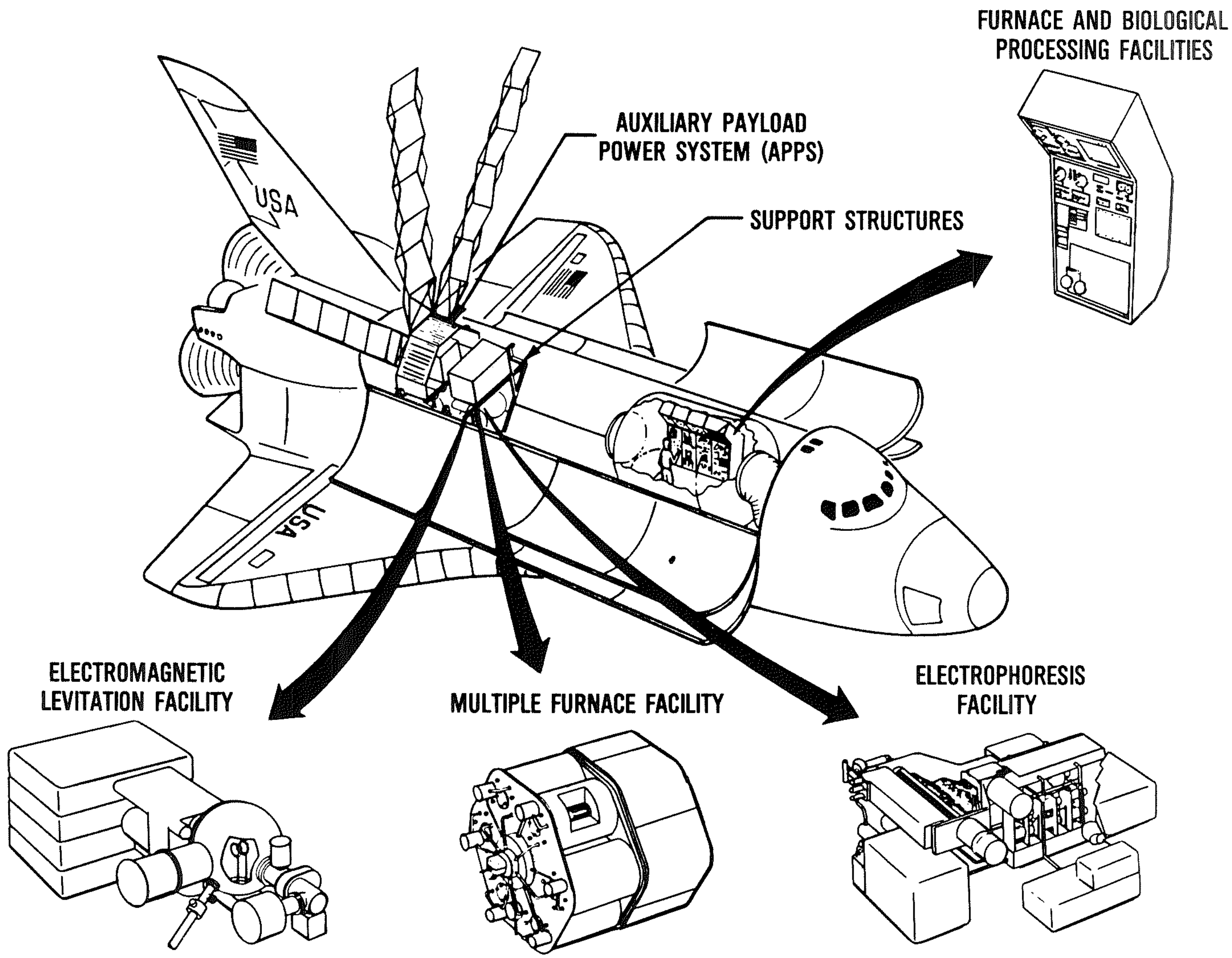

Figure 2.- Space processing of Spacelab payloads.