quencies are distributed like random noise. The ratio of these frequencies is relatively stable (*4*) and expresses the synergetic function of the brain (*5*).

In flight, the ratio of eye movement frequencies higher than 1 per second and those lower than 1 per 2 seconds shows fluctuations which remain within the normal range (Fig. 2). It is of interest that the inflight fluctuations were repeated after return, showing that the variations in gravity were integrated without distinction between increases and decreases in gravity.

The increase in REM discharges on flight night 1 was unexpected. Given the stress of the launch, a decrease was expected instead (*6*). However, the payload specialists for the Spacelab 1 mission had undergone a long period of preparation. They had been thoroughly trained to perform various experiments and they were able to adjust their instructions to novel circumstances. The results are consistent with the view that the change to zero gravity provides information which the brain of PS1 integrated positively. The same was true after landing for the change to normal gravity, but Fig. 2 shows an apparent delay of 1 day in the integration of this new information. The effects of the 12-hour time shift together with the effects of the return to normal gravity may have been responsible for the delay.

There is no doubt that there is a link between eye movements during sleep and those during wakefulness (which were recorded in other experiments on the Spacelab 1 mission). However, the specific link is not yet known. The present results may provide hypotheses for future research.

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Radiobiological Advanced Biostack Experiment

Abstract. *The radiobiological properties of the heavy ions of cosmic radiation were investigated on Spacelab 1 by use of biostacks, monolayers of biological test organisms sandwiched between thin foils of different types of nuclear track detectors. Biostacks were exposed to cosmic radiation at several locations with different shielding environments in the module and on the pallet. Evaluations of the physical and biological components of the experiment to date indicate that in general they survived the spaceflight in good condition. Dosimetric data are presented for the different shielding environments.*

Humans in spaceflight are exposed to two important sources of potentially detrimental effects: (i) the cessation of the gravitational stimulus to which they are normally adapted and (ii) ionizing cosmic radiation. On the earth people in industrial countries are exposed and possibly adapted to an average radiation dose-equivalent estimated as 2.4 millisieverts (mSv) per year (*1*), whereas measurements in the near-earth orbits of Skylab yielded exposure levels between 200 and 800 mSv per year (*2*). It is not this quantitative increase in intensity that merits special attention, however, since according to current radiation protection standards even this several hundredfold increase would not prohibitively limit man's sojourn in space. It is the radiobiological quality of numerically minor components of the cosmic radiation field which uniquely distinguishes it from the terrestrial radiation environment and which, since the beginning of manned spaceflight, has prompted the special attention of radiation biologists (*3*).

In the context of radiation protection the radiobiological quality is expressed in terms of a dimensionless quality factor, Q, by which the amount of physically absorbed radiation as measured in grays (1 Gy = 1 joule/kg) is to be multiplied in order to yield the biologically relevant dose-equivalent in sieverts (*4*). The physical quantity by which ionizing radiations of different quality are conventionally distinguished is the spatial density of ionizations engendered in the irradiated material, which in turn can be expressed by their linear energy transfer (LET), usually given in keV per micrometer of tissue or MeV-cm^2 per gram. The densely ionizing heavy ions [also called HZE (high charge and energy) particles] and the disintegration stars of nuclear reactions induced in irradiated matter present an obstacle to a comprehensive and consistent assessment of the radiation hazards in manned spaceflight. The LET of the cosmic heavy ions extends to such large values, where both the spatial and temporal pattern of energy deposition become extremely inhomogenous, that the very definition of absorbed dose as a measure of radiation exposure and also the concept of the quality factor become inapplicable (*5*). The pragmatic approach of setting aside these fundamental conceptual difficulties and converting the physically measured macroscopic spatial and temporal "averages" of "absorbed dose" distributions over LET into biological "dose-equivalents" by means of accepted Q(LET) relations (*6*) remains problematic, since (i) the data base on which these relations rest does not cover the ionization densities typical of cosmic heavy ions, (ii) LET alone does not provide a unique measure of radiation quality, and (iii) a unified theoretical understanding of radiation quality, which might allow extrapolations, has yet to be achieved. These problems were recognized in a report of the U.S. National Academy of Sciences on HZE particle effects. The report (*7*) concluded that in order to assess the radiation hazards of these HZE particles to man, the experimental knowledge of their radiobiological effects must be advanced by spaceflight experiments and ground-based experiments at suitable particle accelerators (which at that time just became operational). Also, in order to be relevant for this purpose, these experiments must permit evaluation of the radiobiological effects of single HZE particles on individual biological cells.

The advanced biostack experiment on Spacelab 1 is part of a research project designed to contribute toward this goal through spaceflight and comparative accelerator experiments. The physical and biological components of the advanced biostack experiment are listed in (*8*), together with the contributing coinvestigators. The requirement for observing the effects of single HZE particles on individual biological cells was realized for the first time in the biostack experiment on Apollo 16 (*9*). Basically, the experimental design consists of a sand-

wich-like combination of thin foils of different types of tissue-equivalent visual nuclear track detectors of varying sensitivity, interspersed with monolayers of suitable biological test organisms, in such a way that the geometric correlation between the registered tracks of the HZE particles and the individual cells in the vicinity of these tracks could be established. The procedures adopted for this correlation differed widely, depending on the nature of the test organisms and the required precision. A large variety of test organisms, differing in systematic position, organizational level, developmental stage, radiation sensitivity, and size, have been used to provide as broad an empirical basis as possible. These procedures were refined in subsequent spaceflight experiments on the last lunar mission of Apollo 17 (*10*) and the earth-orbital Apollo-Soyuz mission (*11*). However, the results agreed with the most significant finding of the first biostack experiment, that single HZE particles may induce dramatic changes in individual cells, whose resistance exceeds that of mammalian cells by several orders of magnitude. Another common finding was that when the spaceflight data allowed the application of radiobiological models, the models fell significantly short of reproducing the observed effects (*12*); this finding was reproduced in cases where the same methods were used in comparative experiments at accelerators (*13*).

In addition to these radiobiological findings, the biostack spaceflight experiments yield detailed dosimetric results on the atomic composition and LET spectra of the HZE particles as well as the spatial density of nuclear disintegration stars inside the spacecraft. Whereas only one experimental unit was flown inside each Apollo command module, which had rather low mass shielding, the Spacelab 1 mission offered the opportunity to obtain dosimetric data in four experimental units located in different shielding environments, that is, one unit on the pallet, two units in the experimental racks of the module, and one unit beneath the floor of the module. These data are necessary for predictions of radiation hazards in future long-term missions, once the problem of evaluating the radiation quality has had at least an operational solution. They also serve as tests of the rather involved models used to calculate radiation transport under the influence of the geomagnetic shielding effect (*14*).

Preliminary measurements of fluxes (in ions per square centimeter per day) of heavy ions with an LET above ~1 GeV-cm^2/g show an increase from about 0.16 beneath the floor to 0.25 inside the racks and 0.28 on the pallet in one substack of plastic detectors, and an increase from 0.20 in the floor to 0.34 on the pallet in another substack. In a somewhat more sensitive plastic detector the last two fluxes were measured as 0.36 and 0.54, respectively. In nuclear emulsions with a still lower registration threshold a flux of about 1 ion/cm^2-day with an LET above about 400 MeV-cm^2/g was measured on the pallet, where a very heavy ion (atomic number probably twice as large as that of iron) was also detected for the first time in a biostack experiment. Lithium fluoride dosimeters measured average physical absorbed doses of 26.4, 31.7, and 31.0 mGy/year in stacks beneath the floor, within the racks, and on the pallet, respectively. These values, which are mostly produced by sparsely ionizing radiation, show a less marked dependence on the shielding than the heavy ion fluxes. Nuclear disintegration stars registered in emulsions on the pallet at about 750 stars/cm^3-day. All these dosimetric data are consistently somewhat lower than the values for the Apollo-Soyuz mission, where the spacecraft had less shielding. Table 1 summarizes the dosimetric results in comparison with the results of previous biostack experiments. A detailed comparison must await the final calibration of the detector materials and the evaluation of complete LET and particle spectra.

Table 1. Results of dosimetric measurements inside biostack containers. Values are arranged in order of increasing shielding within each experiment.

Biostack experiment	Dose rate in LiF TLD dosimeter (mGy/year)	Heavy-ion flux		Density of nuclear disintegration stars (cm^{-3} day^{-1})
		LET threshold (GeV-cm^2/g)	Flux (cm^{-2} day^{-1})	
Apollo 16	197	1.0	1.45	
	174			1350
	158	1.0	0.87	
Apollo 17	217			
	210	1.0	1.98	1000
	205			
Apollo-Soyuz	50			
	44	1.0	0.50	1440
	39			
Spacelab 1*				
Pallet	31	0.4	1.0	
		0.8	0.54	750
		1	0.28, 0.34	
Racks	32	1	0.25	
Floor	26	0.8	0.36	
		1	0.16, 0.20	

*Preliminary and approximate values.

The biological tests performed so far indicate that the test organisms were not influenced by the experimental and spaceflight conditions as such. Ground controls, which were subjected to a simulated temperature profile of the mission, and flight control cells, which were flown but not hit by heavy ions, showed good survival (generally above 90 percent). An exception was eggs of *Artemia salina*, the test organisms with the largest sensitive volume; as in the previous biostack experiments, the flight controls exhibited only about 50 percent survival. The extent to which this inactivation is a radiobiological effect of nuclear disintegration stars within the eggs, possibly in combination with other factors of the spaceflight environment such as microgravity, remains to be determined. In the eggs which were hit by heavy ions and still formed swimming larvae (~5 percent), development appeared to be more strongly retarded than in previous spaceflight experiments, by approximately a factor of 10 compared to normal eggs. Thin layers of myoglobin and rhodopsin were included for the first time in the advanced biostack experiment as biochemical test systems. Rapid, automated postflight scanning of the dry films at the wavelengths of peak absorbance with a spatial resolution of 2 μm has not so far revealed any new absorbance holes ascribable to heavy-ion trajectories. Experiments are in progress to determine whether post-exposure wetting of the films will modify this finding.

Evaluation of the physical and biological subsystems showed that no component was affected by spaceflight to any degree that might impair its functioning in the experiments. The preliminary dosimetric data already show a distinct dependence on the shielding environ-

ment. Significant radiobiological results from the much more tedious biological subexperiments are to be expected in due course.

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Radiation Measurements Aboard Spacelab 1

Abstract. *The radiation environment inside Spacelab 1 was measured by a set of passive radiation detectors distributed throughout the volume inside the module, in the access tunnel, and outside on the pallet. Measurements of the low-LET (linear energy transfer) component obtained from the thermoluminescence detectors ranged from 102 to 190 millirads, yielding an average low-LET dose rate of 11.2 millirads per day inside the module, about twice the low-LET dose rate measured on previous flights of the space shuttle. Because of the higher inclination of the orbit (57° versus 28.5° for previous shuttle flights), substantial fluxes of highly ionizing HZE particles (high charge and energy galactic cosmic rays) were observed, yielding an overall average mission dose-equivalent of about 150 millirems, more than three times higher that measured on previous shuttle missions.*

It is now generally recognized that perhaps the single most important constraint on long-term manned space activities will be the space radiation environment. The highly penetrating nature of some components of the space radiation field makes it impractical to provide enough shielding to the crew to completely eliminate the hazard. An indirect hazard also comes about from the effects of radiation on materials and electronics, in addition to the soft errors produced in computers. For biomedical experiments performed in space it may be necessary to take possible radiation effects into account. To date, only very limited experimental data exist on the radiation levels and their variation inside orbiting spacecraft (*1–5*).

Spacecraft in earth orbit encounter the complex natural radiation environment consisting of galactic cosmic rays, solar flare particles, trapped charged particles of the radiation belts and secondaries such as proton recoils, neutrons, bremsstrahlung, and other products of the interaction of primaries with the spacecraft shielding materials. In addition, orbiting spacecraft may encounter trapped electrons from high-altitude nuclear tests as well as gammas and neutrons from onboard auxiliary power sources. Much of the radiation environment is modified by the geomagnetic field and by the activity of the sun, resulting in orders of magnitude variation in intensity and significant changes in energy spectra as a function of the orbital parameters of altitude and inclination as well as spacecraft shielding. While computer codes have been developed for calculating the environment inside the orbiting spacecraft in specific orbits, there are uncertainties in the proton models (about a factor of 2), in the electron belt models (about a factor of 5), in fragmentation cross sections of heavy ions, and so on (*6, 7*). In addition, the shielding at any one location within the spacecraft is only approximately known and may vary in time as experimental equipment is moved about, consumables are used up, the location of the crew changes, and the orientation of the spacecraft changes. For these reasons, radiation measurements at specific locations inside the spacecraft are indispensable.

The radiation detector assembly for this experiment consisted of 26 detector packs (*8*) with dimensions of about 10 by