Scientific opposition to the space station is partly the result of its enormous cost. Senator Dale Bumpers (Democrat, Arkansas), who annually tries to kill station funding in Congress, complained last year that: "One shuttle flight to the space station will cost almost as much as the entire $454 million budget of the National Institute on Aging."

The US contribution to hardware development alone is $17.4 billion, with almost $4 billion coming from the European Space Agency (ESA), $2.5 billion from Japan, $1 billion from Canada, a rough estimate of $350 million in annual spending by Russia, plus smaller contributions from junior partners such as Brazil. Depending on how one does the accounting, the bill will run to between $50 billion and $100 billion, all-inclusive, to build, launch and operate the station for a decade or more in orbit. But the view that this money is being taken from space science (or from other science projects) has been generally discredited — no science managers at NASA or ESA headquarters seriously believe they would benefit if the station were cancelled.

Deduct the enormous cost of their orbiting laboratory, and space-based researchers are no richer than their terrestrial colleagues. The grant money NASA gives to scientists in the field of space biomedicine is "trivial," says Jeffrey Borer, a professor of cardiovascular medicine at Cornell University. Borer does not do space-based experiments himself, but chairs a committee overseeing cooperation between NASA and the National Institutes of Health (NIH).

The same holds generally for other kinds of microgravity research. Last autumn, for example, NASA awarded 26 research teams a total of $6 million in five-year grants related to fundamental physics in microgravity, an annual average of only $46,000. In many cases, most of that money goes direct to aerospace companies to build expensive space hardware. If space station experimenters are accused of being pampered, they certainly don't feel as if they are.

They often do feel defensive, however, and embarrassed by press releases and advertisements promising cures for cancer and AIDS from station research. "The space life sciences community has never tried to justify the whole costs of the space station on the basis of our science," says Alain Berthoz, a neuroscientist from the College de France in Paris. Berthoz's group has flown ten space experiments and plans to study spatial perception using virtual reality on the station. "But the station has been built, for whatever reason, and there are interesting questions which can only be answered in zero gravity."

What microgravity offers

Such questions may be few, but they are intriguing. In space, subtle fluid transport and crystallization processes, which are masked by gravity-driven convection on Earth, can be studied in detail. Muscles atrophy, bones lose mineral, fluids shift inside the body, and balance organs cease to work properly.

Some of these conditions are potentially interesting to terrestrial researchers. Examples of experiments that microgravity researchers say could be significant to the general scientific community are:

- *Continuing study of tree-like structures called dendrites in solidifying metals.* Free from the dominating influence of gravity, the dynamics of dendrite formation can be observed on very short time scales (using high-frame-rate video expected to be available on the space station) while experimenters manipulate such variables as temperature and hydrostatic pressure. The work should improve theoretical models of dendrite formation, a key factor in determining the strength and durability of metal alloys.
- *Investigation of the cellular mechanisms behind bone deterioration.* Astronauts lose about one per cent of their bone mass for every month they stay in orbit. Bone deterioration due to spaceflight may be linked to progressive bone diseases such as osteoporosis, but it happens at a much faster rate. Is there a common mechanism? On the space station, researchers could evaluate how different levels of mechanical stress (starting with its near complete absence in weightlessness) affect gene expression in osteoblast cells that promote bone growth. For the first time, scientists will be able to study bone modelling and remodelling in multiple generations of animals that have never experienced gravity.
- *ACES (Atomic Clock Ensemble in Space).* A French-led experiment scheduled to be attached to the outside of the station beginning in 2002, ACES will use microgravity conditions to improve by a factor of ten the accuracy of a laser-cooled caesium atomic clock (which uses the same laser-cooling techniques that won last year's Nobel Prize in physics).

On earth, the atomic clock measures the fundamental oscillation frequencies of caesium atoms during their trajectory in an 'atomic fountain' contained within a one-metre vessel. If the atoms in the fountain are not held back by gravity, they can be launched

No animals allowed for European researchers

European life scientists conducting research on the space station may have to work with a severe handicap compared with their international colleagues: they may not be allowed to use laboratory animals.

Although experiments organized through the European Space Agency (ESA) are paid for by individual member states, the agency itself administers the research programme. And because Germany, the biggest European contributor to the station, is refusing to support the use of animals for experiments in space, ESA has imposed an unwritten rule: no rats, no frogs, no animals of any kind.

"This is a great pity for our [research] community," says Alain Berthoz, a neuroscientist from the College de France in Paris and a veteran space experimenter. One key topic for space biology, he says, is the influence of gravity on neurological development. And that topic, he says, can only be addressed by flying living animals in space.

Didier Schmitt, director of ESA's life sciences department, considers the implications of the moratorium sufficiently problematic to have formed a small task force to consider the issue, and hopes to have it lifted as a general principle. "If we don't do [animal experiments], we will not be able to catch up with the United States and Japan," he says. He wants to convince Germany that scientists from other ESA states should not be prevented from carrying out animal experiments — even if Germany chooses not to fund such experiments itself. European scientists have flown animals on past space missions through agreements with either the United States or Russia. Now that all ESA partners have to agree on rules for the use of ESA facilities on the space station, the issue is more complicated. Schmitt fears that European researchers may react to the moratorium by reaching bilateral agreements with the United States, Russia, or Japan, and that the coherence of ESA's research could suffer.

Banned: unlike the early 1960s (above), primates can no longer fly in the US.

US researchers, meanwhile, will have to operate under separate restrictions. For political reasons, no non-human primates will be allowed on the space station. And that, say life scientists, will rob them of an important research tool, particularly for cardiovascular studies.

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