Perspective

Gamma-Ray Observations of Orbiting Nuclear Reactors

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GAMMA RAYS ARE THE MOST ENERGETIC ELECTROMAGNETic radiation, and are produced in some of the least understood objects in the universe such as supernovae, neutron stars, and quasars. Mysterious gamma-ray bursts were first detected in 1967 by the Vela satellites designed to monitor compliance with the ban on nuclear explosions in space. These bursts are thought to be generated by compact astronomical objects—but neither the identities of the sources nor the gamma-ray production mechanisms are yet known. Because gamma rays are extremely penetrating and travel in straight lines, their study may lead us to an understanding of the sources of energetic cosmic rays. The annihilation of the invisible "dark matter" that makes up a majority of the mass of our galaxy may produce gamma rays whose detection will shed light on its composition. Gamma-ray astronomy is still in its infancy, though it is poised for rapid progress with a new generation of satellite instruments to be launched soon.

Four reports (*1–4*) in this issue of *Science* are the first published presentations of observations of nuclear reactors on earth satellites. Three of the reports (*1–3*) discuss observations by the Gamma-Ray Spectrometer (GRS) on the Solar Maximum Mission (SMM) satellite; the other report (*4*) discusses observations by a sensitive gamma-ray telescope carried by a high-altitude balloon. The SMM-GRS observations began in 1980, when SMM was launched, but have only now been declassified. The balloon-borne instrument observed gamma rays from four different reactors during its 30-hour flight over Australia in April 1988.

These observations are important for several reasons. They confirm earlier reports that the Soviet Union has placed many reactors in orbit and provide independent information about the power of these reactors. The observations show clearly that the gamma rays, electrons, and positrons from orbiting reactors are a troublesome background for gamma-ray astronomy. And by demonstrating that orbiting reactors are essentially impossible to hide, these observations may help lay the groundwork for verifying a proposed ban on orbiting reactors—for which there are also compelling environmental and arms control arguments.

The United States orbited a tiny test reactor in 1965. The Soviet Union has subsequently orbited more than 30 reactors of approximately 100-kW thermal power on their Radar Ocean Reconnaissance Satellites (RORSATs), which are used to track U.S. naval vessels (*5*). Since radar power requirements grow rapidly with range, the RORSATs are placed in extraordinarily low orbits of about 250-km altitude where atmospheric drag would prohibit the use of solar panels. Before each RORSAT reenters the atmosphere after a few months of operation, its reactor is usually boosted to a long-lived orbit at 950 km. This boost system failed on Cosmos 954, whose reactor reentered over northern Canada in 1978, and on Cosmos 1402, whose reactor reentered over the South Atlantic Ocean in 1983 (*6*); reentry of the reactor on the malfunctioning Cosmos 1900 was narrowly averted in September 1988 when a backup system worked. In 1987 the Soviet Union launched two reactors of slightly higher power into orbits of about 800-km altitude on the satellites they called Cosmos 1818 and 1867; it is these reactors that have caused the most interference with SMM. Meanwhile, the United States has been developing a space reactor of approximately 2.5-MW thermal power, named SP-100, primarily for advanced Strategic Defense Initiative (SDI) satellites.

These orbiting reactors are extremely bright sources of gamma rays since they are essentially unshielded except in the direction of the payload (*7*). Gamma rays from all four of the operating reactors in orbit in April 1988 were readily imaged by the sensitive University of California at Riverside Compton gamma-ray telescope during its 30-hour balloon flight (*4*). When they are overhead, the RORSAT reactors are 50 times brighter than the Crab nebula, the brightest astronomical gamma-ray source in the sky (*4*).

Reactor gamma rays were also detected many times by the SMM-GRS. But the main signal detected by SMM from orbiting reactors was from positrons and electrons (*1–3*), since these charged particles are trapped in the geomagnetic field and can be detected many minutes after they are emitted. They could not be detected by the balloon-borne detector, however, because they do not penetrate the atmosphere as much as gamma rays do. Positrons are pair-produced by the reactor gamma rays exiting the spacecraft skin; electrons are emitted by pair-production and Compton scattering. Both electrons and positrons spiral around lines of the geomagnetic field, bouncing back and forth between northern and southern mirror points and drifting in longitude, until they are eventually depleted by collisions with atoms of the upper atmosphere. This theory is convincingly confirmed by the beautiful detailed agreement between its predictions and the SMM observations of these charged particles (*2, 3*). Because of their higher orbits, the charged particles from Cosmos 1818 and 1867 were longer lived and were therefore detected more frequently by SMM than those from the RORSATs (*2*).

Gamma-ray detectors are surrounded by charged-particle detectors, so that events initiated by gamma rays can be distinguished from background events initiated by electrons. But positrons can annihilate on other parts of the gamma-ray detector spacecraft such as the SMM shield, and the resulting 511-keV gamma rays can appear to be true gamma-ray signals. The data storage capacity of the SMM-GRS was saturated by such signals an average of eight times per day for much of 1987 and early 1988, and it was effectively blinded for the rest of each orbit until the data could be transmitted to the ground. The much more sensitive detectors aboard Gamma Ray Observatory, scheduled for launch in 1990, and on other ambitious x-ray and gamma-ray satellites, could also be adversely affected, especially the GRO Burst and Transient Source Experiment (BATSE). This problem may be mitigated by turning the detectors off when such satellites are about to pass through a geomagnetically trapped shell of reactor-emitted charged particles, whose location can be predicted by the methods developed by the SMM investigators (*3*). But if many powerful reactors are in orbit, as contemplated for advanced stages of SDI, this approach would probably be inadequate to protect gamma-ray astronomy in low earth orbit.

A more effective way to avoid this problem would be to stop placing reactors in orbit. The Joint Study on Verification, cochaired by Frank von Hippel and Roald Sagdeev under the auspices of the

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Federation of American Scientists and the Committee of Soviet Scientists for Peace, called for a ban on further launches of orbiting reactors in May 1988; legislation to enact such a ban has been introduced by Representative George E. Brown, Jr. (D–CA), and many cosponsors (*8*). A working group of which I have been a leader has prepared several technical reports (*7, 9–11*) showing that such a ban would be verifiable since operating reactors must emit a great deal of infrared radiation (*9, 10*) as well as nuclear radiation. It would also have numerous arms control and environmental advantages.

The possibilities of reactor reentry causing contamination of the earth's surface and the atmosphere have already been demonstrated by Cosmos 954 and 1402. There is also the possibility of nuclear proliferation. Space reactors are fueled with essentially pure uranium-235, the rare fissionable isotope that can be used to make nuclear weapons. The SP-100 design requires about 200 kg of uranium-235, many times the quantity required to make a bomb. Accidental return of an intact reactor to the earth's surface because of launch failure or a loss of orbit would thus provide enough fuel to make several weapons. An international race to recover uranium could ensue if a reactor reenters. Since reactors are not turned on until they reach orbit, a launch accident or failure to reach orbit could provide nonradioactive nuclear materials that even terrorists could convert to weapons. While the SDI organization has proposed retrieving errant reactors or boosting them to higher orbits, a reactor that has collided with another object in space or has been attacked by an anti-satellite weapon might reenter before there is time to rescue it.

Unshielded nuclear reactors are used to power military satellites because they are lighter, more compact, and more survivable than any other long-lived power source. A ban on orbiting reactors would mean trading off the reactors being developed for SDI against continued deployment of Soviet RORSATs and the Soviet program to develop larger orbiting reactors. Such a ban would be among the most easily verifiable ways of supplementing and strengthening the Anti-Ballistic Missile (ABM) Treaty of 1972. A ban would not only restrict weapons in space but could also eliminate a principal U.S. incentive to develop anti-satellite weapons (ASATs), since RORSATs are presently the main target of the proposed ASATs.

President Jimmy Carter proposed a ban on orbiting reactors in the wake of the 1978 RORSAT reentry, but the Soviet Union rejected the idea. In view of the strong interest of the Soviet government in avoiding an arms race in space, now is a good time for the United States to propose a ban again, as both sides have much to gain.

Unshielded nuclear reactors are such strong sources of radiation that human presence anywhere near them is impossible. I know of no civilian orbital application that requires nuclear power. A ban on orbiting reactors would not preclude the use of reactors in deep space. They may be essential for powering ambitious unmanned spacecraft to explore the solar system's outer reaches, where solar energy is faint. Reactors may also be an appropriate source of power for a manned lunar base. They would have considerably less mass than the solar energy storage devices required by the 14-day lunar night at all locations except the lunar poles. However, a reactor designed specifically to be implanted in the lunar soil for shielding would probably be quite different from SP-100.

Only military uses are currently contemplated for space reactors for at least the next decade. In order to prevent the development and testing of a space reactor intended for military use under the guise of a civilian program, it might be best to begin with a complete ban on space reactors for, say, 10 years. By then, the U.S.–U.S.S.R. relationship might have improved enough to make testing of space reactors for civilian missions less threatening. Removing the military link to space reactors may make cooperative international missions using them possible.

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