

## Miniature Radioisotope Thermoelectric Power Cubes

These devices could supply power at extremely low temperatures for years.

NASA's Jet Propulsion Laboratory, Pasadena, California

Cube-shaped thermoelectric devices energized by a particles from radioactive decay of  $^{244}\text{Cm}$  have been proposed as long-lived sources of power. These power cubes are intended especially for incorporation into electronic circuits that must operate in dark, extremely cold locations (e.g., polar locations or deep underwater on Earth, or in deep interplanetary space). Unlike conventional radioisotope thermoelectric generators used heretofore as central power sources in some spacecraft, the proposed power cubes would be small enough (volumes would range between 0.1 and 0.2  $\text{cm}^3$ ) to play the roles of batteries that are parts of, and dedicated to, individual electronic-circuit packages. Unlike electrochemical batteries, these power cubes would perform well at low temperatures. They would also last much longer: given that the half-life of  $^{244}\text{Cm}$  is 18 years, a power cube could remain adequate as a power source for years, depending on the power demand in its particular application.

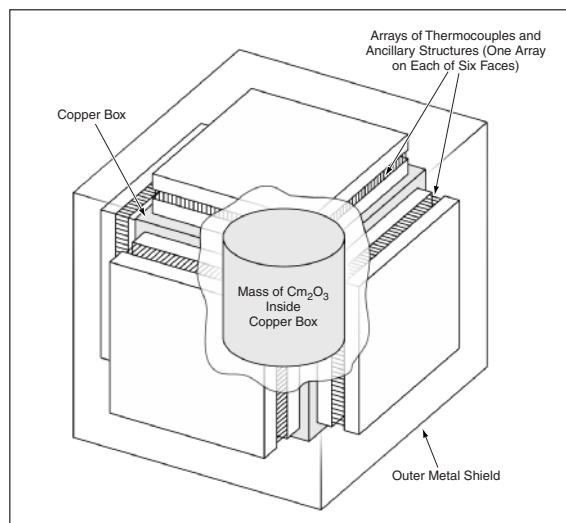
The cubical configuration of a proposed device of this type (see figure) would contribute to thermal efficiency by providing a relatively large area for rejection of heat at low temperature. It would also contribute to thermal-to-electrical energy-conversion efficiency by providing a relatively large heat-transfer area that could be covered with arrays of thermocouples and maximiz-

ing the temperature drop across the thermoelectric elements.

The geometric and thermal heart of a proposed thermoelectric power cube would be a cubic box, made of porous copper, that would enclose a mass of about 0.5 g of  $^{244}\text{Cm}$  in oxide form. The wall thickness of the box [ $\approx 20$  mils ( $\approx 0.5$  mm)] would be sufficient to stop the  $\alpha$  particles and contain any ancillary radioactivity. The deposition of radioactive-decay energy in the walls of the box would generate heat at the rate of 4.2 W initially, falling to 2.1 W in 18 years. At the initial rate and under typical anticipated operating conditions, this heating would maintain the temperature of the box at about 200 °C.

Thin-film arrays of thermocouples would be mounted on all six faces of the box for efficient conversion of heat into electricity. The portion of the power cube described thus far would be enclosed in a layer of metal that would serve as both a shield and a heat-sinking interface with the environment. The metal shield would also help to contain small amounts of soft  $\gamma$  radiation and neutrons that are emitted from the  $^{244}\text{Cm}$  along with the  $\alpha$  particles.

According to first estimates, each face



A Power Cube according to the proposal would be designed to exploit synergies among small size, the cubical configuration, and low ambient temperature to obtain relatively high energy-conversion efficiency.

would be covered with about 50 thermocouples that would generate 40 mW of power (a potential of 2 V at a current of 20 mA). Hence, the total electric power produced would be 240 mW, corresponding to an overall thermal-to-electrical energy-conversion efficiency of between 5 and 6 percent.

*This work was done by Jagdish U. Patel, Jean-Pierre Fleurial, G. Jeffrey Snyder, and Thierry Caillat of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30328*

## Permanent Sequestration of Emitted Gases in the Form of Clathrate Hydrates

Hydrates would be formed under natural conditions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Underground sequestration has been proposed as a novel method of permanent disposal of harmful gases emitted into the atmosphere as a result of human activity. The method was conceived primarily for disposal of carbon dioxide

( $\text{CO}_2$ , greenhouse gas causing global warming), but could also be applied to  $\text{CO}$ ,  $\text{H}_2\text{S}$ ,  $\text{NO}_x$ , and chlorofluorocarbons (CFCs, which are super greenhouse gases). The method is based on the fact that clathrate hydrates (e.g.,  $\text{CO}_2 \cdot 6\text{H}_2\text{O}$ )

form naturally from the substances in question (e.g.,  $\text{CO}_2$ ) and liquid water in the pores of sub-permafrost rocks at stabilizing pressures and temperatures. The proposed method would be volumetrically efficient: In the case of  $\text{CO}_2$ , each

volume of hydrate can contain as much as 184 volumes of gas.

Temperature and pressure conditions that favor the formation of stable clathrate hydrates exist in depleted oil reservoirs that lie under permafrost. For example,  $\text{CO}_2\cdot 6\text{H}_2\text{O}$  forms naturally at a temperature of  $0^\circ\text{C}$  and pressure of 1.22 MPa. Using this measurement, it has been calculated that the minimum thickness of continuous permafrost needed to stabilize  $\text{CO}_2$  clathrate hydrate is only about 100 m, and the base of the permafrost is known to be considerably deeper at certain locations (e.g., about 600 m at Prudhoe Bay in Alaska). In this disposal method, the permafrost layers over the

reservoirs would act as impermeable lids that would prevent dissociation of the clathrates and diffusion of the evolved gases up through pores.

Because the natural pressure and temperature conditions in suitably chosen reservoirs would favor the formation of clathrates, no additional energy would be needed, other than the energy for pumping the gases into the reservoirs. There would also be no need to drill holes into the reservoirs: instead, the holes and other infrastructure already in place (and used previously to extract the oil from the reservoirs) would henceforth be used to inject the gases into the reservoirs.

As an additional benefit, pumping of  $\text{CO}_2$  could help to maintain the pressure necessary for extraction of oil from an adjacent reservoir that had not yet been depleted. At present, natural gas is used for this purpose. The use of  $\text{CO}_2$  instead of natural gas would make it possible to recover more natural gas as fuel. Moreover, unlike natural gas,  $\text{CO}_2$  does not pose an explosion hazard.

*This work was done by N. Duxbury of Caltech and V. Romanovsky of the University of Alaska at Fairbanks for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-30256*

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## Electrochemical, $\text{H}_2\text{O}_2$ -Boosted Catalytic Oxidation System

**This system offers several advantages over  $\text{O}_2$ -boosted systems.**

*Lyndon B. Johnson Space Center, Houston, Texas*

An improved water-sterilizing aqueous-phase catalytic oxidation system (APCOS) is based partly on the electrochemical generation of hydrogen peroxide ( $\text{H}_2\text{O}_2$ ). This  $\text{H}_2\text{O}_2$ -boosted system offers significant improvements over prior dissolved-oxygen water-sterilizing systems in the way in which it increases oxidation capabilities, supplies  $\text{H}_2\text{O}_2$  when needed, reduces the total organic carbon (TOC) content of treated water to a low level, consumes less energy than prior systems do, reduces the risk of contamination, and costs less to operate. This system was developed as a variant of part of an improved waste-management subsystem of the life-support system of a spacecraft. Going beyond its original intended purpose, it offers the advantage of being able to produce  $\text{H}_2\text{O}_2$  on demand for surface sterilization and/or decontamination: this is a major advantage inasmuch as the benign byproducts of

this  $\text{H}_2\text{O}_2$  system, unlike those of systems that utilize other chemical sterilants, place no additional burden of containment control on other spacecraft air- or water-reclamation systems.

This system produces  $\text{H}_2\text{O}_2$  in an electrochemical/electrodialytic process that consumes only electrical energy and oxygen; that is, unlike some other systems, this system consumes no expensive chemicals. The system includes an  $\text{H}_2\text{O}_2$  generator, an  $\text{H}_2\text{O}_2$ -pervaporation membrane, and an APCOS reactor.

Tests have verified that  $\text{H}_2\text{O}_2$  can be easily transferred and delivered from a stream identical to that in the central compartment of an electrochemical cell to a required process stream. Test results have also shown that at stoichiometric concentrations,  $\text{H}_2\text{O}_2$  promotes the increased destruction of urea and of  $\text{NH}_3$  (the chief byproduct of urea) in wastewater. Heretofore,  $\text{NH}_3$  has been consid-

ered one of the more intractable contaminants for oxidation purposes. Data indicate that oxidation occurs at high rates at low temperatures — an important advantage in that the consumption of energy is reduced and safety increased, relative to prior oxygen-boosted systems that must operate at higher temperatures. Moreover, the ability of this system to oxygenate highly contaminated wastewater was proved by the nearly complete oxidation of 500 mg/L of acetic acid (TOC = 200 mg/L). Considered together, these data are a convincing argument for using electrochemically produced  $\text{H}_2\text{O}_2$  to boost APCOS oxidation rates in highly contaminated wastewater.

*This work was done by James R. Akse, John O. Thompson, and Leonard J. Schussel of Umpqua Research Co. for Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.  
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## Electrokinetic *In Situ* Treatment of Metal-Contaminated Soil

**This is an alternative to excavation and to techniques dependent on hydraulic conductivity.**

*John F. Kennedy Space Center, Florida*

An electrokinetic technique has been developed as a means of *in situ* remediation of soils, sludges, and sediments that are contaminated with heavy metals. Examples of common metal contaminants that can be removed by this technique include cad-

mium, chromium, zinc, lead, mercury, and radionuclides. Some organic contaminants can also be removed by this technique.

In the electrokinetic technique, a low-intensity direct current is applied between electrodes that have been im-

planted in the ground on each side of a contaminated soil mass. The electric current causes electro-osmosis and migration of ions, thereby moving aqueous-phase subsurface contaminants from one electrode to the other. The half reaction