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Solar Detoxification Technology: Using Energy from the Sun to Destroy Hazardous Waste

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ABSTRACT ■ *Solar energy is being applied to one of the most difficult environmental problems our country faces in the coming decades: the destruction of hazardous waste. Researchers within the U.S. Department of Energy's Solar Industrial Program are developing two separate technologies—solar detoxification of water and solar decontamination of soil—that could revolutionize the way toxic wastes are removed from the environment. Unlike many remediation techniques in use today, these solar-based processes actually destroy hazardous contaminants; the wastes are not transferred to other media for disposal.*

Solar detoxification of water, which is currently undergoing an extended field test at a Superfund site in California, uses solar energy to power a reaction that eliminates organic contaminants from polluted surface water and groundwater. The process uses a solar-activated photocatalyst, such as titanium dioxide, to break the bonds holding organic compounds together. Researchers are currently working to increase the efficiency and reduce the costs of the process to make it economically competitive with traditional remediation methods. Commercialization of the solar detoxification of water process could occur by the middle of this decade.

In a related program researchers are investigating the ability of high solar flux (upwards of 300 times the sun's normal intensity) to decontaminate polluted solids such as soils. The DOE is working closely with the Environmental Protection Agency and the Department of Defense in developing this technology. The solar decontamination of soil is a two-step process: in the first step contaminants are desorbed from the solid either by solar thermal energy or by conventional means (such as heating or vacuum extraction); in the second step the desorbed contaminants are destroyed. The contaminants can be destroyed by using either a high-flux photolytic process or a low-flux process that employs a photocatalyst. SERI's state-of-the-art high-flux solar furnace is home to a large portion of the soil decontamination research.

■ INTRODUCTION

The general public is painfully aware of the dangerous health and environmental effects of hazardous waste in the United States. Few, if any, environmental problems generate greater public concern or can affect the quality of our lives more dramatically than the existence of toxic substances in our environment. All 50 states have toxic waste problems that must be addressed. While traditional remediation methods are being successfully employed in the fight against toxic waste, new methods of eliminating hazardous waste using clean, renewable energy from the sun may soon enter the battle to reclaim our environment: the Department of Energy's (DOE's) solar detoxification technologies are coming of age.

The DOE, through its Solar Industrial Program, is currently funding two related solar detoxification research projects—solar detoxification of water and solar decontamination of soil. The technologies bring together state-of-the-art solar energy research with the practical needs of the environmental remediation industry. Applying environmentally benign solar energy to the problems of toxic waste has created an attractive and beneficial union; contaminated areas can be reclaimed without expending additional fossil-fuel-based energy. While both solar detox technologies are currently in the development stage, they could reach the commercial market by mid-1990s.

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The Solar Industrial Program is part of the DOE's Waste Material Management Division, which is within the office of Industrial Technology. The Solar Energy Research Institute (SERI) manages the program, and technical activities are carried out at Sandia National Laboratories and SERI.

Solar Detoxification of Water

The solar detoxification of water could revolutionize the way in which polluted surface water and groundwater are reclaimed. Many of our water resources are polluted with volatile organic compounds, dioxins, and pesticides. Solar decontamination destroys these hazardous chemicals by using the energy available from sunlight. Polluted water is brought into contact with a semiconducting photocatalyst, such as titanium dioxide, which in the presence of sunlight creates highly reactive hydroxyl radicals. These radicals react with the organic contaminants and convert them into water, carbon dioxide, and easily neutralized mineral acids such as hydrochloric acid. Because the process requires low solar intensities, the reaction can be initiated using either a flat-channel apparatus or a transparent tube mounted at the focus of a parabolic reflecting trough (up to 30-sun concentrations). This latter design is shown in Figure 1.

The first field test of the solar decontamination process began in July 1991 at a Superfund site on the grounds of the Lawrence Livermore National Laboratory (LLNL) in Livermore, California. During World War II the grounds now occupied by LLNL were home to a naval air station training and maintenance facility. Normal operations included cleaning engine parts with trichloroethylene (TCE), a toxic degreasing solvent. Over the years, uncontained TCE and other volatile organic compounds entered the local groundwater, where they are now slowly migrating off site. Along with three DOE laboratories, a number of private industrial parties are participating in developing and testing the detox system.

The field test will occur in two phases: Phase I, currently under way, consists of a small-scale, skid-mounted system set up to gather data on the site-specific conditions at LLNL and to monitor the initial performance of the decontamination system. Phase II, scheduled to begin later this fall, will significantly expand the test by incorporating the lessons learned in Phase I, the ongoing developments from industry and DOE research, and advanced control systems, reactor designs, and catalysts. The test is scheduled to run for approximately 1 year.

The solar detoxification system is operating upstream of a commercial decontamination system currently in use at LLNL; this eases problems with permitting and potential contamination release because all process water will still be treated with LLNL's existing treatment system. Conversely, researchers must implement and monitor additional system controls that ensure the water exiting the solar-based system is within the pH and temperature range at which the conventional decontamination system operates. An artist's conception of the initial field setup is shown in Figure 2.

The field test at LLNL will not only provide researchers with valuable data leading to process improvements and reduced costs, but will also be an indicator that solar decontamination of surface water and groundwater containing toxic organic compounds can be a viable alternative to conventional decontamination methods.

Solar Decontamination of Soil

Managing, treating, and remediating polluted solids are controversial topics. Traditional remediation methods, including incineration and landfill disposal, continue to be a source of heated debate and often are energy-intensive operations. Researchers are currently developing remediation methods driven by solar power that are free from the undesirable side effects of conventional techniques and exceed the destruction and removal efficiency standards set by the Environmental Protection Agency (EPA).

SERI's high-flux solar furnace serves as one of the primary facilities for research in the solar decontamination of soil. The solar furnace began operating in early 1990 and allows researchers to study the properties and applications of very high solar concentrations. Figure 3 shows the physical configuration of the solar furnace. The heliostat tracks the sun and reflects incoming solar energy onto the stationary primary concentrator, which consists of 23 individual curved facets (see Figure 4). These facets collectively focus a 10-centimeter-diameter concentrated beam of solar flux at a point in the test facility. The detoxification research requires 300 to 1000 times the normal solar intensity, which is only a fraction of what the furnace is capable of producing.

The high-flux solar furnace is used to study a photolytic soil decontamination process. This process uses energy from both ends of the solar spectrum. Typically, a concentration of greater than 300 suns is required to power the reaction. The contaminants are desorbed from the solid using either vacuum extrac-

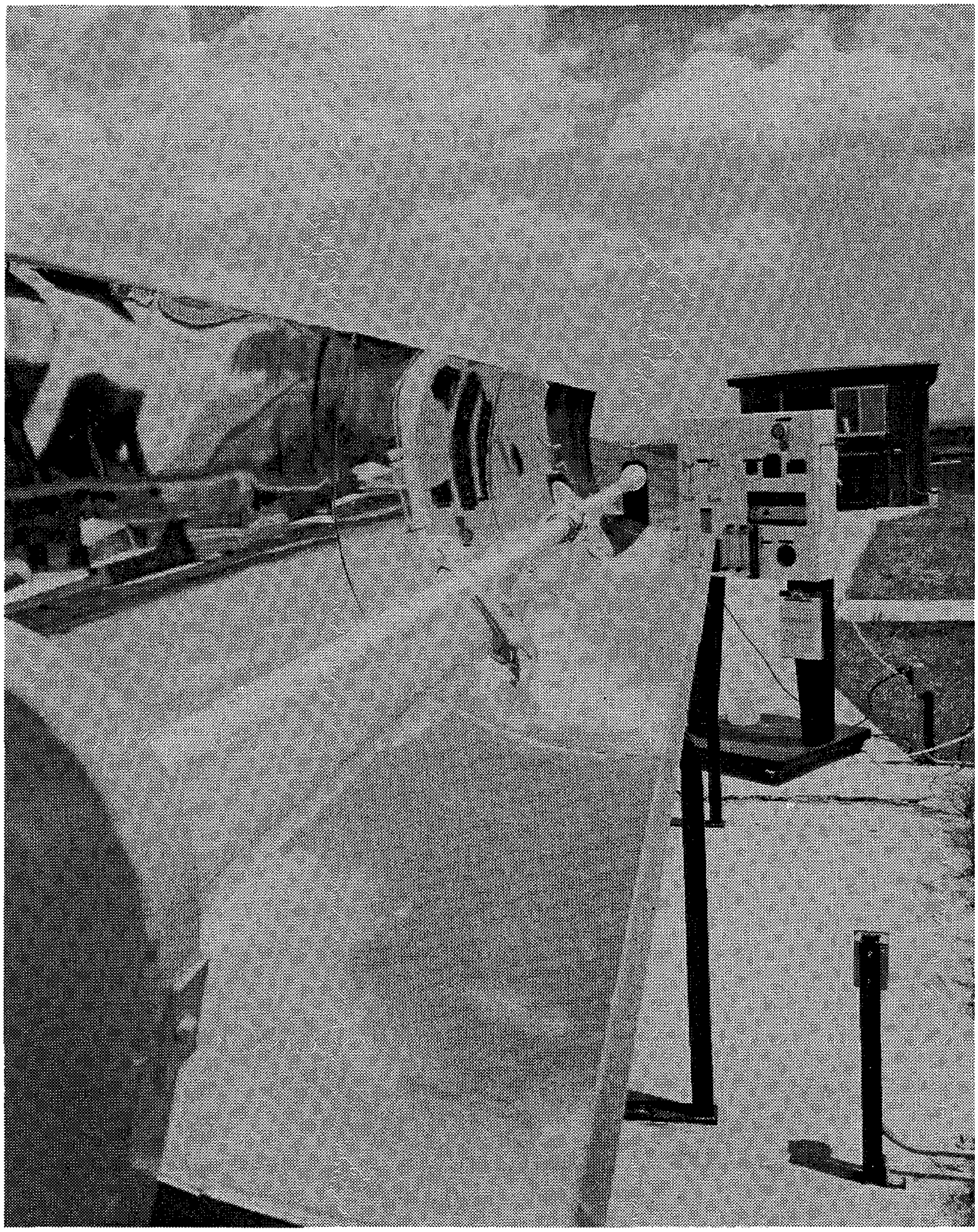

Figure 1. Experimental Solar Decontamination Trough.

tion or heat (heat produced by the infrared portion of the solar spectrum can be used for this purpose). After being desorbed the contaminants are introduced into a reactor (shown in Figure 5) that is mounted at the focus of a solar concentrator system. The near-ultraviolet portion (high-energy photons) of the flux then destroys the contaminants, resulting in end products such as CO_2, H_2O, and HCl.

The second method of soil decontamination is a photocatalytic process that has produced promising results in destroying volatile organic compounds such as TCE, perchloroethylene (PCE), and other contaminants. This is a low-flux, low-temperature process that is currently being studied using a trough collector system, although the process can be performed in a flat-channel system. After the contam-

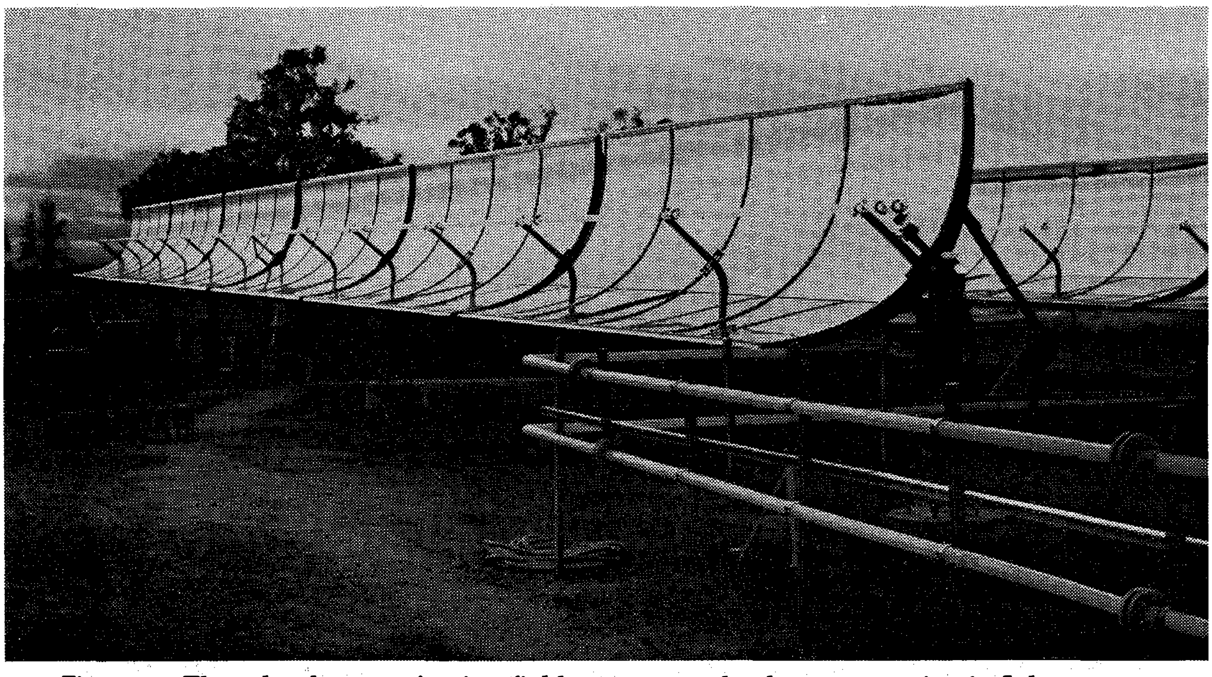

Figure 2. The solar decontamination field test system that began operating in July, 1991.

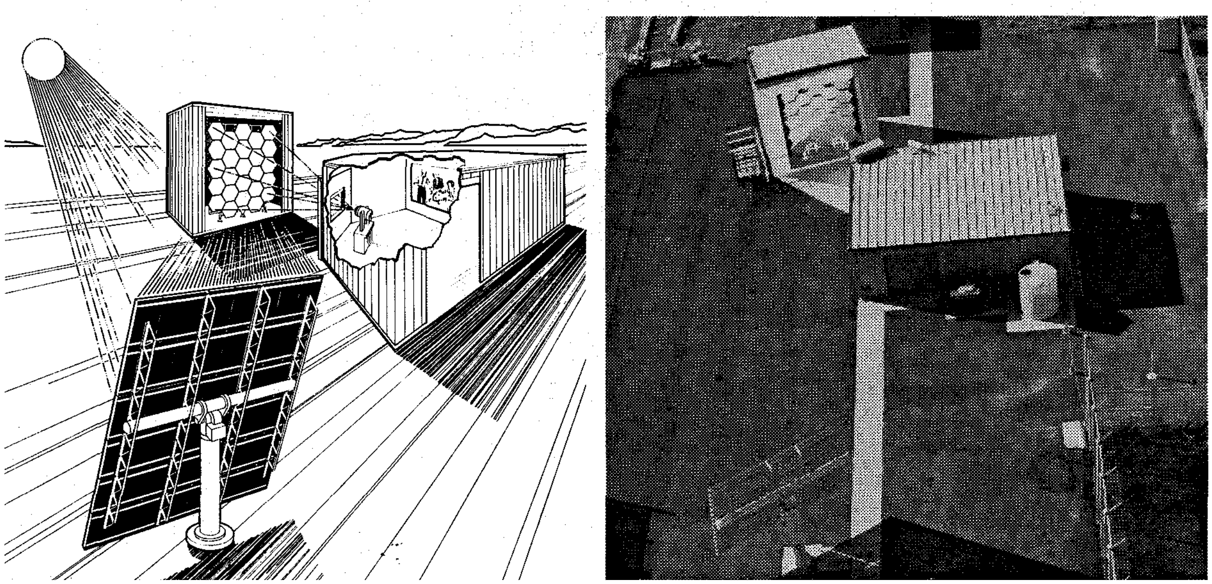

Figure 3. SERI's high-flux solar furnace. Left: Schematic view of system operation. Right: The actual facility located on South Table Mountain in Golden, Colorado.

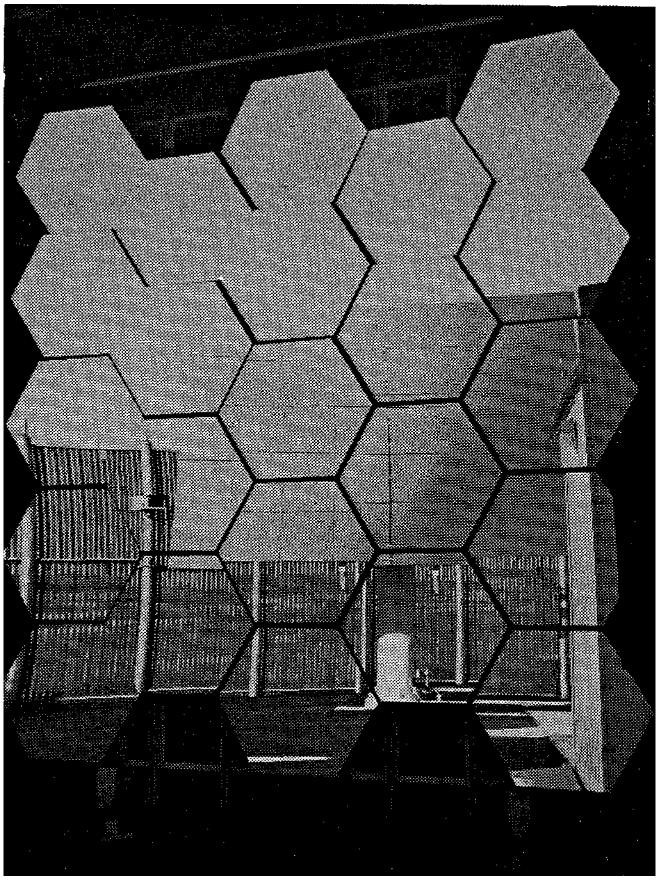

Figure 4. The primary concentrator of SERI's solar furnace. The 23 enhanced-aluminum front-surface mirrors focus the reflected solar flux to a 10-cm-diameter beam inside the test building (not shown). The reflection of the heliostat, which tracks the sun and directs its energy to the concentrator, is shown.

inants are desorbed (once again using vacuum or thermal extraction methods) from the soil, the gaseous product is pumped through a tube mounted at the focus of a trough-type solar collector. The photocatalyst, titanium dioxide, is present on a fixed support inset in the tube. In the presence of sunlight the photocatalyst breaks the bonds holding the toxic molecules together. Preliminary results indicate the process should be highly economical because of the extremely fast reaction rates between the contaminants and the photocatalyst; this suggests large amounts of contaminants can be destroyed using a relatively small setup.

Both of these methods are remarkably efficient in destroying gaseous organics (exceeding the EPA's 99.9999% requirement), and neither produce the detrimental by-products associated with conventional incineration techniques. By the latter part of this decade these methods could become standard tools in the environmental remediation and waste management industries.

The soil decontamination research is being sponsored by three federal agencies: the U.S. Department of Energy (DOE), the U.S. Department of Defense (DOD), and the U.S. Environmental Protection Agency (EPA). The technology is attractive to all three parties for different reasons. The DOD is interested in applying the process to soil remediation at Army facilities. The EPA is exploring the new technology for potential nonmilitary use, and the DOE is interested in the technology as a means to reduce energy consumption and increase the economic competiveness of U.S. industry.

■ CONCLUSION

The solar detoxification technologies will give the environmental waste management industry new, powerful tools to destroy wastes with clean energy from the sun. The near-term research will improve the efficiencies and pave the way for the transfer of these techniques to private industry. By the end of this decade we hope that a large portion of the nation's hazardous toxic waste will be eliminated using the solar detoxification processes.

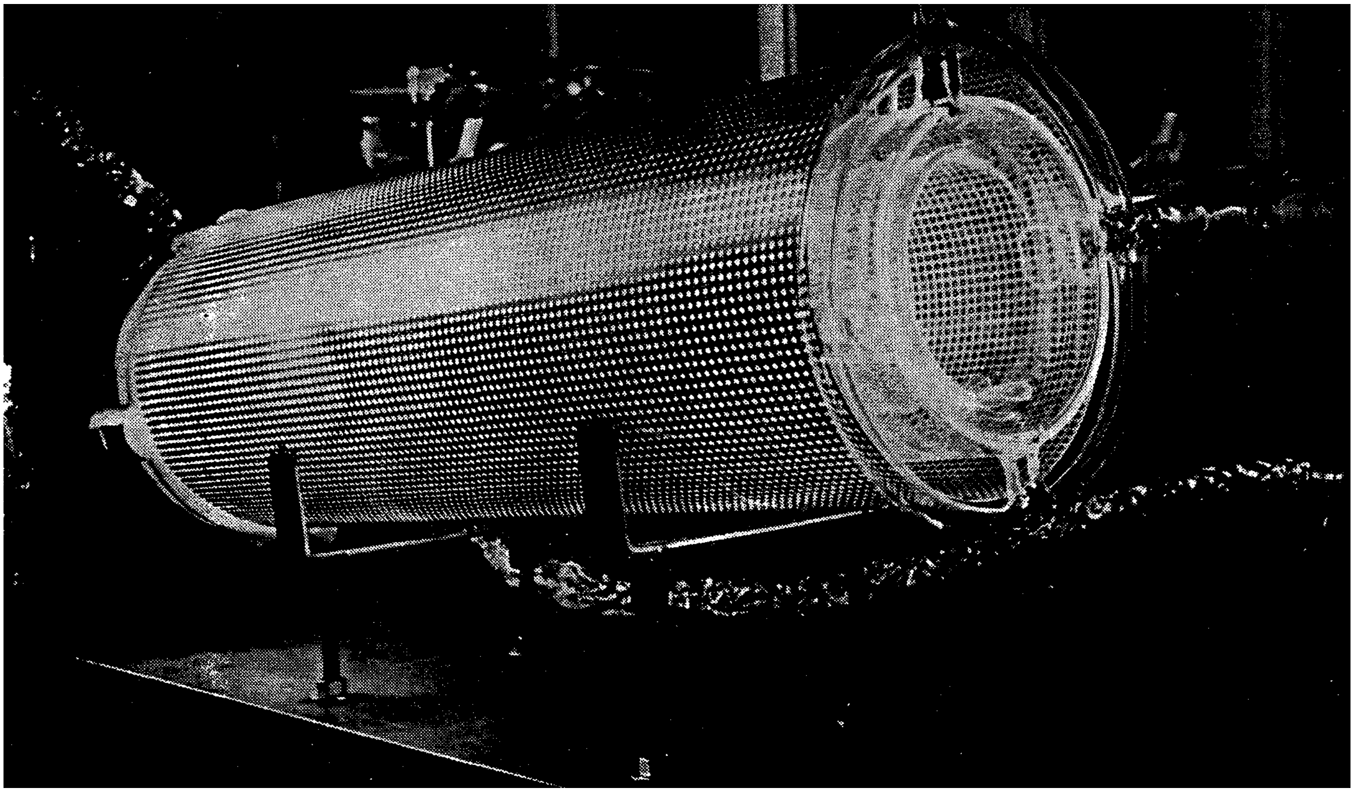

Figure 5. Solar Detox Reactor