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CRITICAL INFRASTRUCTURE PROTECTION

Challenges and Efforts to Secure Control Systems

Statement of Robert F. Dacey,
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March 30, 2004

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GAO Highlights

Highlights of GAO-04-628T, a testimony before the Subcommittee on Technology, Information Policy, Intergovernmental Relations and the Census, House Committee on Government Reform

Why GAO Did This Study

Computerized control systems perform vital functions across many of our nation's critical infrastructures. For example, in natural gas distribution, they can monitor and control the pressure and flow of gas through pipelines. In October 1997, the President's Commission on Critical Infrastructure Protection emphasized the increasing vulnerability of control systems to cyber attacks. At the request of the House Committee on Government Reform, Subcommittee on Technology, Information Policy, Intergovernmental Relations and the Census, this testimony will discuss GAO's March 2004 report on potential cyber vulnerabilities, focusing on (1) significant cybersecurity risks associated with control systems (2) potential and reported cyber attacks against these systems (3) key challenges to securing control systems, and (4) efforts to strengthen the cybersecurity of control systems.

What GAO Recommends

In a March 2004 report, GAO recommends that the Secretary of the Department of Homeland Security (DHS) develop and implement a strategy for coordinating with the private sector and other government agencies to improve control system security, including an approach for coordinating the various ongoing efforts to secure control systems. DHS concurred with GAO's recommendation.

www.gao.gov/cgi-bin/getrpt?GAO-04-628T.

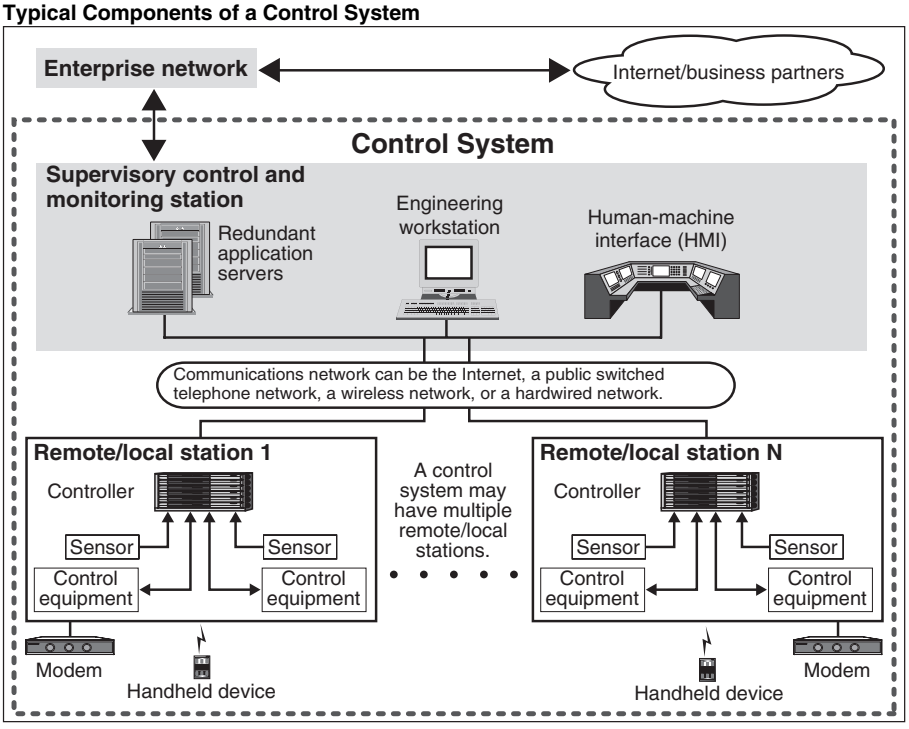
To view the full product, including the scope and methodology, click on the link above. For more information, contact Robert F. Dacey at (202) 512-3317 or daceyr@gao.gov.

What GAO Found

In addition to general cyber threats, which have been steadily increasing, several factors have contributed to the escalation of the risks of cyber attacks against control systems. These include the adoption of standardized technologies with known vulnerabilities and the increased connectivity of control systems to other systems. Typical control system components are illustrated in the graphic below. Control systems can be vulnerable to a variety of attacks, examples of which have already occurred. Successful attacks on control systems could have devastating consequences, such as endangering public health and safety.

Securing control systems poses significant challenges, including limited specialized security technologies and lack of economic justification. The government, academia, and private industry have initiated efforts to strengthen the cybersecurity of control systems. The President's *National Strategy to Secure Cyberspace* establishes a role for DHS to coordinate with these entities to improve the cybersecurity of control systems. While some coordination is occurring, DHS's coordination of these efforts could accelerate the development and implementation of more secure systems. Without effective coordination of these efforts, there is a risk of delaying the development and implementation of more secure systems to manage our critical infrastructures.

Typical Components of a Control System



Source: GAO (analysis), Art Explosion (clipart).

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to participate in the Subcommittee's hearing on the cyber vulnerabilities in industrial control systems. Control systems—which include supervisory control and data acquisition (SCADA) systems and distributed control systems[1]—perform vital functions across many of our nation's critical infrastructures, including electric power generation, transmission, and distribution; oil and gas refining and pipelines; water treatment and distribution; chemical production and processing; railroads and mass transit; and manufacturing. In October 1997, the President's Commission on Critical Infrastructure Protection highlighted the risk of cyber attacks as a specific point of vulnerability in our critical infrastructures, stating that "the widespread and increasing use of SCADA systems for control of energy systems provides increasing ability to cause serious damage and disruption by cyber means."

In my testimony today I will discuss the results of our recent report, which is being released today.[2] As you requested, this report identifies (1) significant cybersecurity risks associated with control systems, (2) potential and reported cyber attacks against these systems, (3) key challenges to securing control systems, and (4) efforts to strengthen the cybersecurity of control systems.

In preparing our report, we analyzed research studies and reports, as well as prior GAO reports and testimonies on critical infrastructure protection (CIP), information security, and national preparedness, among others. We analyzed documents from and met with private-sector and federal officials who had expertise in control systems and their security. Our work was performed from July 2003 to March 2004 in accordance with generally accepted government auditing standards.

[1]Control systems are computer-based systems that are used by many infrastructures and industries to monitor and control sensitive processes and physical functions. Typically, control systems collect sensor measurements and operational data from the field, process and display this information, and relay control commands to local or remote equipment. There are two primary types of control systems. Distributed Control Systems (DCS) typically are used within a single processing or generating plant or over a small geographic area. Supervisory Control and Data Acquisition (SCADA) systems typically are used for large, geographically dispersed distribution operations.

[2]U.S. General Accounting Office, *Critical Infrastructure Protection: Challenges and Efforts to Secure Control Systems*, GAO-04-354 (Washington, D.C.: March 15, 2004).

Results in Brief

For several years, security risks have been reported in the control systems on which many of the nation's critical infrastructures rely to monitor and control sensitive processes and physical functions. In addition to a steady increase in general cyber threats, several factors have contributed to the escalation of risks specific to control systems, including the (1) adoption of standardized technologies with known vulnerabilities, (2) connectivity of control systems with other networks, (3) insecure remote connections, and (4) widespread availability of technical information about control systems.

Control systems can be vulnerable to a variety of types of cyber attacks that could have devastating consequences—such as endangering public health and safety; damaging the environment; or causing a loss of production, generation, or distribution by public utilities. Control systems have already been subject to a number of cyber attacks, including attacks on a sewage treatment system in Australia in 2000 and, more recently, on a nuclear power plant in Ohio.

Securing control systems poses significant challenges. These include the limitations of current security technologies in securing control systems, the perception that securing control systems may not be economically justifiable, and conflicting priorities within organizations regarding the security of control systems.

Government, academia, and private industry have initiated several efforts that are intended to improve the security of control systems. These initiatives include efforts to promote the research and development of new technologies, the development of requirements and standards, an increased awareness and sharing of information, and the implementation of effective security management programs. The President's *National Strategy to Secure Cyberspace* establishes a role for the Department of Homeland Security (DHS) to coordinate with the private sector and other governments to improve the cybersecurity of control systems. While some coordination is occurring, DHS's coordination of these efforts could accelerate the development and implementation of more secure systems. Without adequate coordination of these efforts, there is a risk of delaying the development and implementation of more secure systems to manage our critical infrastructures.

In our March report, we recommend that the Secretary of DHS develop and implement a strategy for coordinating with the private sector and

other government agencies to improve control system security, including developing an approach for coordinating the various ongoing efforts to secure control systems. This strategy should also be addressed in the comprehensive national infrastructure plan that the department is tasked to complete by December 2004. DHS's concurred with our recommendation and agreed that improving the security of control systems against cyberattack is a high priority.

Background

Cyberspace Introduces Risks for Control Systems

Dramatic increases in computer interconnectivity, especially in the use of the Internet, continue to revolutionize the way our government, our nation, and much of the world communicate and conduct business. The benefits have been enormous. Vast amounts of information are now literally at our fingertips, facilitating research on virtually every topic imaginable; financial and other business transactions can be executed almost instantaneously, often 24 hours a day, and electronic mail, Internet Web sites, and computer bulletin boards allow us to communicate quickly and easily with an unlimited number of individuals and groups.

However, this widespread interconnectivity poses significant risks to the government's and our nation's computer systems and, more important, to the critical operations and infrastructures they support. For example, telecommunications, power distribution systems, water supplies, public health services, national defense (including the military's warfighting capability), law enforcement, government services, and emergency services all depend on the security of their computer operations. If they are not properly controlled, the speed and accessibility that create the enormous benefits of the computer age may allow individuals and organizations to eavesdrop on or interfere with these operations from remote locations for mischievous or malicious purposes, including fraud or sabotage. Table 1 summarizes the key threats to our nation's infrastructures, as observed by the Federal Bureau of Investigation (FBI).

Table 1: Threats to Critical Infrastructures Observed by the FBI

Threat	Description
Criminal groups	There is an increased use of cyber intrusions by criminal groups who attack systems for monetary gain.
Foreign intelligence services	Foreign intelligence services use cyber tools as part of their information gathering and espionage activities.
Hackers	Hackers sometimes crack into networks for the thrill of the challenge or for bragging rights in the hacker community. While remote cracking once required a fair amount of skill or computer knowledge, hackers can now download attack scripts and protocols from the Internet and launch them against victim sites. Thus, while attack tools have become more sophisticated, they have also become easier to use.
Hacktivists	Hacktivism refers to politically motivated attacks on publicly accessible Web pages or e-mail servers. These groups and individuals overload e-mail servers and hack into Web sites to send a political message.
Information warfare	Several nations are aggressively working to develop information warfare doctrine, programs, and capabilities. Such capabilities enable a single entity to have a significant and serious impact by disrupting the supply, communications, and economic infrastructures that support military power—impacts that, according to the Director of Central Intelligence, can affect the daily lives of Americans across the country.[a]
Insider threat	The disgruntled organization insider is a principal source of computer crimes. Insiders may not need a great deal of knowledge about computer intrusions because their knowledge of a victim system often allows them to gain unrestricted access to cause damage to the system or to steal system data. The insider threat also includes outsourcing vendors.
Virus writers	Virus writers are posing an increasingly serious threat. Several destructive computer viruses and "worms" have harmed files and hard drives, including the Melissa macro virus, the Explore.Zip worm, the CIH (Chernobyl) virus, Nimda, and Code Red.

Source: Federal Bureau of Investigation, unless otherwise indicated.

[a]Prepared statement of George J. Tenet, Director of Central Intelligence, before the Senate Select Committee on Intelligence, February 2, 2000.

Government officials remain concerned about attacks from individuals and groups with malicious intent, such as crime, terrorism, foreign intelligence gathering, and acts of war. According to the FBI, terrorists, transnational criminals, and intelligence services are quickly becoming aware of and using information exploitation tools such as computer viruses, Trojan horses, worms, logic bombs, and eavesdropping sniffers that can destroy, intercept, degrade the integrity of, or deny access to

data.[3] In addition, the disgruntled organization insider is a significant threat, because these individuals often have knowledge about the organization and its system that allows them to gain unrestricted access and inflict damage or steal assets without knowing a great deal about computer intrusions. As larger amounts of money and more sensitive economic and commercial information are exchanged electronically, and as the nation's defense and intelligence communities increasingly rely on standardized information technology (IT), the likelihood increases that information attacks will threaten vital national interests.

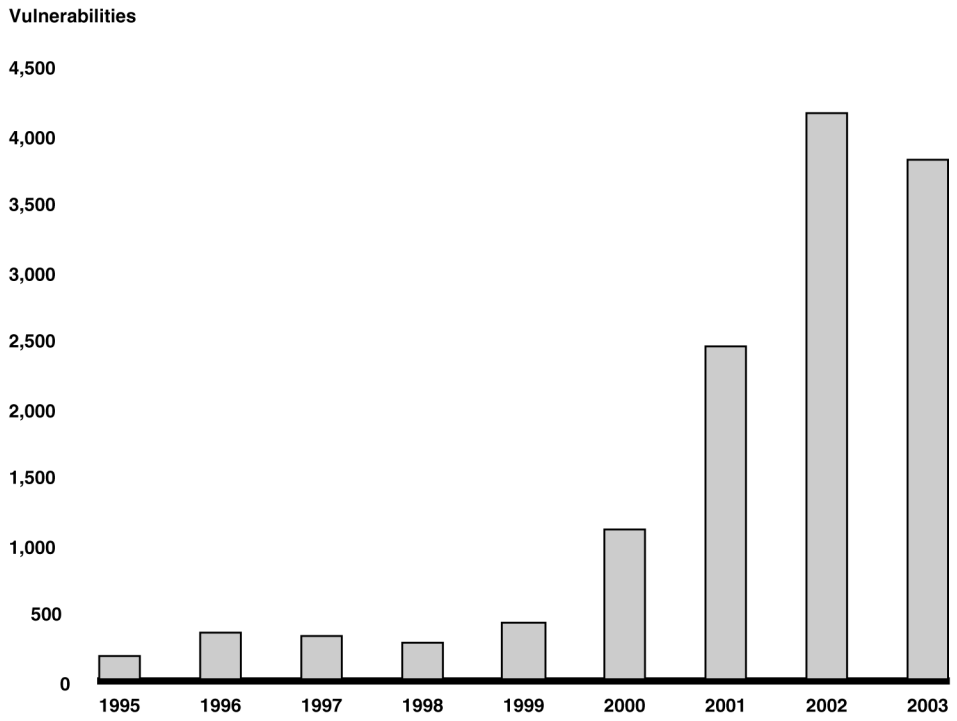
As the number of individuals with computer skills has increased, more intrusion or "hacking" tools have become readily available and relatively easy to use. A hacker can download tools from the Internet and literally "point and click" to start an attack. Experts agree that there has been a steady advance in the level of sophistication and effectiveness of attack technology. Intruders quickly develop attacks to exploit vulnerabilities that have been discovered in products, use these attacks to compromise computers, and share them with other attackers. In addition, they can combine these attacks with other forms of technology to develop programs that automatically scan networks for vulnerable systems, attack them, compromise them, and use them to spread the attack even further.

From 1995 through 2003, the CERT® Coordination Center[4] (CERT/CC) reported 12,946 security vulnerabilities that resulted from software flaws. Figure 1 illustrates the dramatic growth in security vulnerabilities over these years. The growing number of known vulnerabilities increases the potential for attacks by the hacker community. Attacks can be launched against specific targets or widely distributed through viruses and worms.

[3]*Virus*: a program that "infects" computer files, usually executable programs, by inserting a copy of itself into the file. These copies are usually executed when the "infected" file is loaded into memory, allowing the virus to infect other files. Unlike the computer worm, a virus requires human involvement (usually unwitting) to propagate. *Trojan horse*: a computer program that conceals harmful code. A Trojan horse usually masquerades as a useful program that a user would wish to execute. *Worm*: an independent computer program that reproduces by copying itself from one system to another across a network. Unlike computer viruses, worms do not require human involvement to propagate. *Logic bomb*: in programming, a form of sabotage in which a programmer inserts code that causes the program to perform a destructive action when some triggering event occurs, such as termination of the programmer's employment. *Sniffer*: synonymous with packet sniffer. A program that intercepts routed data and examines each packet in search of specified information, such as passwords transmitted in clear text.

[4]The CERT/CC is a center of Internet security expertise at the Software Engineering Institute, a federally funded research and development center operated by Carnegie Mellon University.

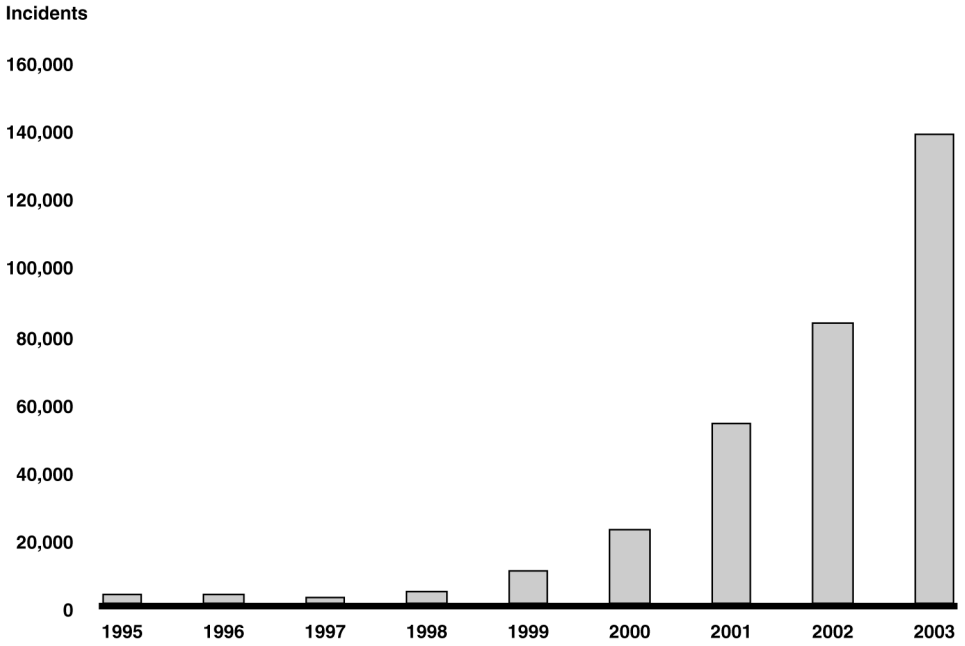
Figure 1: Security Vulnerabilities, 1995–2003



Source: GAO analysis based on Carnegie Mellon University's CERT® Coordination Center data.

Along with these increasing vulnerabilities, the number of computer security incidents reported to CERT/CC has also risen dramatically—from 9,859 in 1999 to 82,094 in 2002 and to 137,529 in 2003. And these are only the reported attacks. The Director of the CERT Centers has estimated that as much as 80 percent of actual security incidents goes unreported, in most cases because (1) there were no indications of penetration or attack, (2) the organization was unable to recognize that its systems had been penetrated, or (3) the organization was reluctant to report. Figure 2 shows the number of incidents that were reported to the CERT/CC from 1995 through 2003.

Figure 2: Computer Security Incidents, 1995–2003



Source: GAO analysis based on Carnegie Mellon University's CERT® Coordination Center data.

According to the National Security Agency (NSA), foreign governments already have or are developing computer attack capabilities, and potential adversaries are developing a body of knowledge about U.S. systems and methods to attack these systems. The National Infrastructure Protection Center (NIPC) reported in January 2002 that a computer belonging to an individual who had indirect links to Osama bin Laden contained computer programs that indicated that the individual was interested in the structural engineering of dams and other water-retaining structures. The NIPC report also stated that U.S. law enforcement and intelligence agencies had received indications that Al Qaeda members had sought information about control systems from multiple Web sites, specifically on water supply and wastewater management practices in the United States and abroad.

Since the terrorist attacks of September 11, 2001, warnings of the potential for terrorist cyber attacks against our critical infrastructures have increased. For example, in his February 2002 statement for the Senate Select Committee on Intelligence, the Director of Central Intelligence

discussed the possibility of a cyber warfare attack by terrorists.[5] He stated that the September 11 attacks demonstrated the nation's dependence on critical infrastructure systems that rely on electronic and computer networks. Further, he noted that attacks of this nature would become an increasingly viable option for terrorists as they and other foreign adversaries become more familiar with these targets and the technologies required to attack them. James Woolsey, a former Director of Central Intelligence, shares this concern, and on October 29, 2003, in a speech before several hundred security experts, he warned that the nation should be prepared for continued terrorist attacks on our critical infrastructures. Moreover, a group of concerned scientists warned President Bush in a letter that "the critical infrastructure of the United States, including electrical power, finance, telecommunications, health care, transportation, water, defense and the Internet, is highly vulnerable to cyber attack. Fast and resolute mitigating action is needed to avoid national disaster." According to a study by a computer security organization, during the second half of 2003, critical infrastructure industries such as power, energy, and financial services experienced high attack rates.[6] Further, a study that surveyed over 170 security professionals and other executives concluded that, across industries, respondents believe that a large-scale cyber attack in the United States will be launched against their industry by mid-2006.

What Are Control Systems?

Control systems are computer-based systems that are used within many infrastructures and industries to monitor and control sensitive processes and physical functions. Typically, control systems collect sensor measurements and operational data from the field, process and display this information, and relay control commands to local or remote equipment. In the electric power industry, control systems can manage and control the generation, transmission, and distribution of electric power— for example, by opening and closing circuit breakers and setting thresholds for preventive shutdowns. Employing integrated control systems, the oil and gas industry can control the refining operations at a plant site, remotely monitor the pressure and flow of gas pipelines, and control the flow and pathways of gas transmission. Water utilities can

[5]Testimony of George J. Tenet, Director of Central Intelligence, before the Senate Select Committee on Intelligence, February 6, 2002.

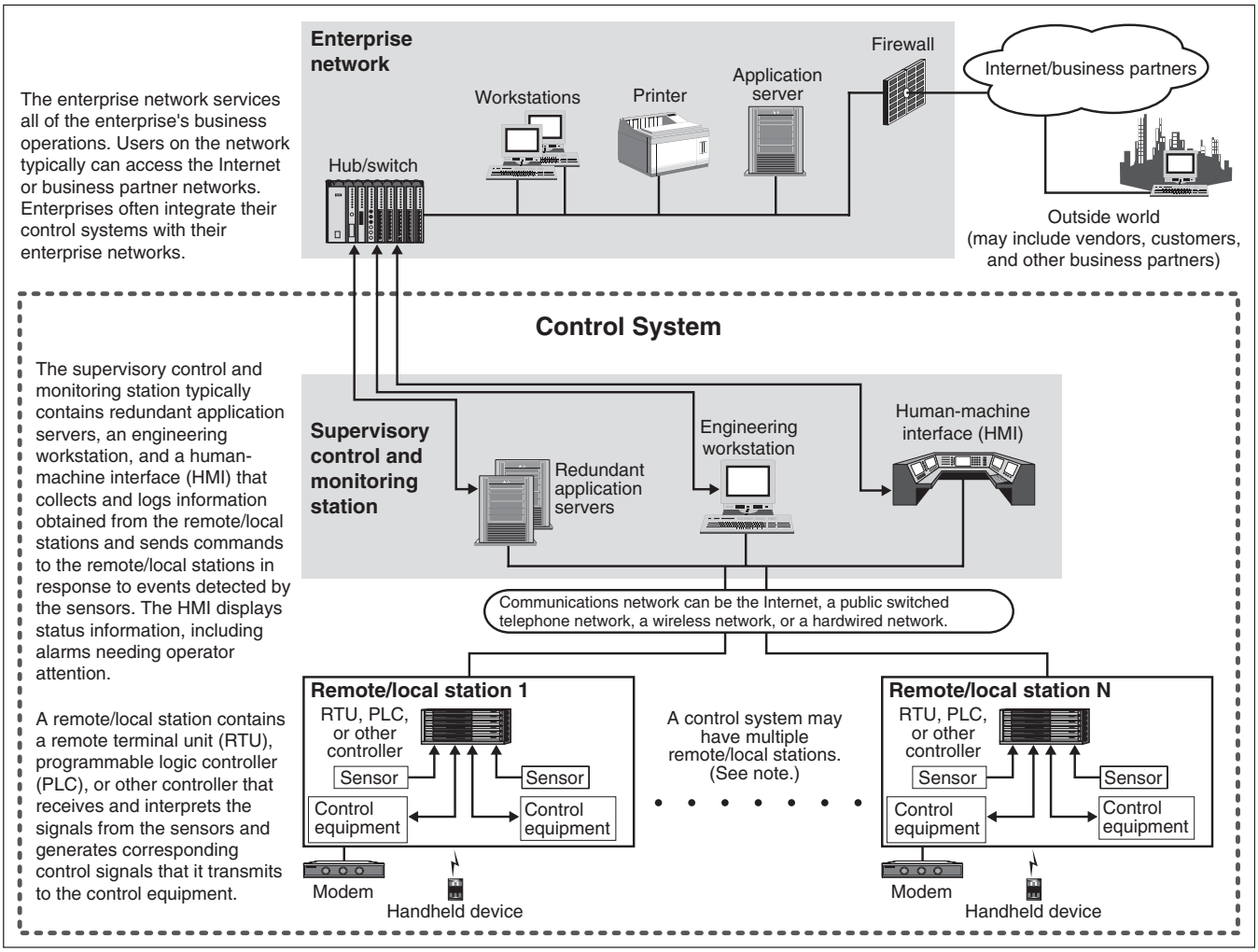
[6]Symantec, *Symantec Internet Security Threat Report: Trends for July 1, 2003-December 31, 2003* (March 2004).

remotely monitor well levels and control the wells' pumps; monitor flows, tank levels, or pressure in storage tanks; monitor water quality characteristics—such as pH, turbidity, and chlorine residual; and control the addition of chemicals. Control systems also are used in manufacturing and chemical processing. Control systems perform functions that vary from simple to complex; they can be used simply to monitor processes—for example, the environmental conditions in a small office building—or to manage most activities in a municipal water system or even a nuclear power plant.

In certain industries, such as chemical and power generation, safety systems are typically implemented in order to mitigate a potentially disastrous event if control and other systems should fail. In addition, to guard against both physical attack and system failure, organizations may establish backup control centers that include uninterruptible power supplies and backup generators.

There are two primary types of control systems. Distributed Control Systems (DCS) typically are used within a single processing or generating plant or over a small geographic area. Supervisory Control and Data Acquisition (SCADA) systems typically are used for large, geographically dispersed distribution operations. For example, a utility company may use a DCS to generate power and a SCADA system to distribute it. Figure 3 illustrates the typical components of a control system.

Figure 3: Typical Components of a Control System



Source: GAO (analysis), Art Explosion (clipart).

Note: Remote/local stations can include one or more interfaces to allow field operators to perform diagnostic and maintenance operations. Sensors can measure level, pressure, flow, current, voltages, etc., depending on the infrastructure. Control equipment can be valves, pumps, relays, circuit breakers, etc., also depending on the infrastructure.

A control system typically is made up of a "master" or central supervisory control and monitoring station consisting of one or more human-machine interfaces where an operator can view status information about the remote/local sites and issue commands directly to the system. Typically, this station is located at a main site, along with application servers and an engineering workstation that is used to configure and troubleshoot the other components of the control system. The supervisory control and

monitoring station typically is connected to local controller stations through a hard-wired network or to a remote controller station through a communications network—which could be the Internet, a public switched telephone network, or a cable or wireless (e.g., radio, microwave, or Wi-Fi[7]) network. Each controller station has a remote terminal unit (RTU), a programmable logic controller (PLC), or some other controller that communicates with the supervisory control and monitoring station.

The control system also includes sensors and control equipment that connect directly with the working components of the infrastructure—for example, pipelines, water towers, or power lines. The sensor takes readings from the infrastructure equipment—such as water or pressure levels, electrical voltage or current—and sends a message to the controller. The controller may be programmed to determine a course of action and send a message to the control equipment instructing it what to do—for example, to turn off a valve or dispense a chemical. If the controller is not programmed to determine a course of action, the controller communicates with the supervisory control and monitoring station and relays instructions back to the control equipment. The control system also can be programmed to issue alarms to the operator when certain conditions are detected. Handheld devices, such as personal digital assistants, can be used to locally monitor controller stations. Experts report that technologies in controller stations are becoming more intelligent and automated and are able to communicate with the supervisory central monitoring and control station less frequently, thus requiring less human intervention.

Control Systems Are at Increasing Risk

Historically, security concerns about control have been related primarily to protecting them against physical attack and preventing the misuse of refining and processing sites or distribution and holding facilities. However, more recently, there has been a growing recognition that control systems are now vulnerable to cyber attacks from numerous sources, including hostile governments, terrorist groups, disgruntled employees, and other malicious intruders.

In October 1997, the President's Commission on Critical Infrastructure Protection discussed the potential damaging effects on the electric power

[7]Wi-Fi (short for wireless fidelity) is the popular term for a high-frequency wireless local area network.

and oil and gas industries of successful attacks on control systems.[8] Moreover, in 2002, the National Research Council identified "the potential for attack on control systems" as requiring "urgent attention."[9] In the first half of that year, security experts reported that 70 percent of energy and power companies experienced at least one severe cyber attack. In February 2003, the President clearly demonstrated concern about "the threat of organized cyber attacks capable of causing debilitating disruption to our Nation's critical infrastructures, economy, or national security," noting that "disruption of these systems can have significant consequences for public health and safety" and emphasizing that the protection of control systems has become "a national priority."[10]

Several factors have contributed to the escalation of risk to control systems, including (1) the adoption of standardized technologies with known vulnerabilities, (2) the connectivity of control systems to other networks, (3) insecure remote connections, and (4) the widespread availability of technical information about control systems.

Control Systems Are Adopting Standardized Technologies with Known Vulnerabilities

In the past, proprietary hardware, software, and network protocols made it difficult to understand how control systems operated—and therefore how to hack into them. Today, however, to reduce costs and improve performance, organizations have been transitioning from proprietary systems to less expensive, standardized technologies such as Microsoft's Windows, Unix-like operating systems, and the common networking protocols used by the Internet. These widely-used, standardized technologies have commonly known vulnerabilities, and sophisticated and effective exploitation tools are widely available and relatively easy to use. As a consequence, both the number of people with the knowledge to wage attacks and the number of systems subject to attack have increased. Also, common communication protocols and the emerging use of extensible markup language (commonly referred to as XML) can make it easier for a hacker to interpret the content of communications among the components of a control system.

[8]President's Commission on Critical Infrastructure Protection, *Critical Foundations: Protecting America's Infrastructures* (Washington, D.C.: October 1997).

[9]The National Research Council, Making the Nation Safer: the Role of Science and Technology in Countering Terrorism (Washington, D.C.: December 2002).

[10]The White House, *The National Strategy to Secure Cyberspace* (Washington, D.C.: February 2003).

Control Systems Are Connected to Other Networks

Enterprises often integrate their control systems with their enterprise networks. This increased connectivity has significant advantages, including providing decision makers with access to real-time information and allowing engineers to monitor and control the process control system from different points on the enterprise network. In addition, the enterprise networks are often connected to the networks of strategic partners and to the Internet. Furthermore, control systems are increasingly using wide area networks and the Internet to transmit data to their remote or local stations and individual devices. This convergence of control networks with public and enterprise networks potentially creates further security vulnerabilities in control systems. Unless appropriate security controls are deployed in both the enterprise network and the control system network, breaches in enterprise security can affect the operation of control systems.

Insecure Connections Exacerbate Vulnerabilities

Vulnerabilities in control systems are exacerbated by insecure connections. Organizations often leave access links—such as dial-up modems to equipment and control information—open for remote diagnostics, maintenance, and examination of system status. If such links are not protected with authentication or encryption, the risk increases that hackers could use these insecure connections to break into remotely controlled systems. Also, control systems often use wireless communications systems, which are especially vulnerable to attack, or leased lines that pass through commercial telecommunications facilities. Without encryption to protect data as it flows through these insecure connections or authentication mechanisms to limit access, there is little to protect the integrity of the information being transmitted.

Information about Infrastructures and Control Systems Is Publicly Available

Public information about infrastructures and control systems is readily available to potential hackers and intruders. The availability of this infrastructure and vulnerability data was demonstrated last year by a George Mason University graduate student who, in his dissertation, reportedly mapped every business and industrial sector in the American economy to the fiber-optic network that connects them, using material that was available publicly on the Internet—and not classified.

In the electric power industry, open sources of information—such as product data and educational videotapes from engineering associations—can be used to understand the basics of the electrical grid. Other publicly

available information—including filings of the Federal Energy Regulatory Commission (FERC), industry publications, maps, and material available on the Internet—is sufficient to allow someone to identify the most heavily loaded transmission lines and the most critical substations in the power grid. Many of the electric utility officials who were interviewed for the National Security Telecommunications Advisory Committee's Information Assurance Task Force's Electric Power Risk Assessment expressed concern over the amount of information about their infrastructure that is readily available to the public.

In addition, significant information on control systems is publicly available—including design and maintenance documents, technical standards for the interconnection of control systems and RTUs, and standards for communication among control devices—all of which could assist hackers in understanding the systems and how to attack them. Moreover, there are numerous former employees, vendors, support contractors, and other end users of the same equipment worldwide who have inside knowledge about the operation of control systems.

Security experts have stated that an individual with very little knowledge of control systems could gain unauthorized access to a control system using a port scanning tool and a factory manual that can be easily found on the Internet and that contains the system's default password. As noted in the following discussion, many times these default passwords are never changed.

Cyber Threats to Control Systems

There is a general consensus—and increasing concern—among government officials and experts on control systems about potential cyber threats to the control systems that govern our critical infrastructures. As components of control systems increasingly make vital decisions that were once made by humans, the potential effect of a cyber attack becomes more devastating. Cyber threats could come from numerous sources ranging from hostile governments and terrorist groups to disgruntled employees and other malicious intruders. Based on interviews and discussions with representatives from throughout the electric power industry, the Information Assurance Task Force of the National Security Telecommunications Advisory Committee concluded that an organization with sufficient resources, such as a foreign intelligence service or a well-supported terrorist group, could conduct a structured attack on the

electric power grid electronically, with a high degree of anonymity, and without having to set foot in the target nation.

In July 2002, NIPC reported that the potential for compound cyber and physical attacks, referred to as "swarming attacks," was an emerging threat to the critical infrastructure of the United States. As NIPC reports, the effects of a swarming attack include slowing or complicating the response to a physical attack. For instance, a cyber attack that disabled the water supply or the electrical system, in conjunction with a physical attack, could deny emergency services the necessary resources to manage the consequences of the physical attack—such as controlling fires, coordinating response, and generating light.

According to the National Institute of Standards and Technology (NIST), cyber attacks on energy production and distribution systems—including electric, oil, gas, and water treatment, as well as on chemical plants containing potentially hazardous substances—could endanger public health and safety, damage the environment, and have serious financial implications such as loss of production, generation, or distribution by public utilities; compromise of proprietary information; or liability issues. When backups for damaged components are not readily available (e.g., extra-high-voltage transformers for the electric power grid), such damage could have a long-lasting effect. I will now discuss potential and reported cyber attacks on control systems, as well as challenges to securing them.

Control Systems Can Be Vulnerable to Cyber Attacks

Entities or individuals with malicious intent might take one or more of the following actions to successfully attack control systems:

- disrupt the operation of control systems by delaying or blocking the flow of information through control networks, thereby denying availability of the networks to control system operators;
- make unauthorized changes to programmed instructions in PLCs, RTUs, or DCS controllers, change alarm thresholds, or issue unauthorized commands to control equipment that could potentially result in damage to equipment (if tolerances are exceeded), premature shutdown of processes (such as prematurely shutting down transmission lines), or even disabling control equipment;
- send false information to control system operators either to disguise unauthorized changes or to initiate inappropriate actions by system operators;

- modify the control system software, producing unpredictable results; and
- interfere with the operation of safety systems.

In addition, in control systems that cover a wide geographic area, the remote sites often are not staffed and may not be physically monitored. If such remote systems were to be physically breached, attackers could establish a cyber connection to the control network.

Department of Energy (DOE) and industry researchers have speculated on how the following potential attack scenario could affect control systems in the electricity sector. Using war dialers[11] to find modems connected to the programmable circuit breakers of the electric power control system, hackers could crack passwords that control access to the circuit breakers and could change the control settings to cause local power outages and even damage equipment. A hacker could lower settings from, for example, 500 amperes[12] to 200 on some circuit breakers; normal power usage would then activate, or "trip," the circuit breakers, taking those lines out of service and diverting power to neighboring lines. If, at the same time, the hacker raised the settings on these neighboring lines to 900 amperes, circuit breakers would fail to trip at these high settings, and the diverted power would overload the lines and cause significant damage to transformers and other critical equipment. The damaged equipment would require major repairs that could result in lengthy outages.

Control system researchers at DOE's national laboratories have developed systems that demonstrate the feasibility of a cyber attack on a control system at an electric power substation where high-voltage electricity is transformed for local use. Using tools that are readily available on the Internet, they are able to modify output data from field sensors and take control of the PLC directly in order to change settings and create new output. These techniques could enable a hacker to cause an outage, thus incapacitating the substation.

Experts in the water industry consider control systems to be among the primary vulnerabilities of drinking water systems. A technologist from the water distribution sector has demonstrated how an intruder could hack into the communications channel between the control center of a water distribution pump station and its remote units, located at water storage

[11]War dialers are simple personal computer programs that dial consecutive phone numbers looking for modems.

[12]An ampere is a unit of measurement for electric current.

and pumping facilities, to either block messages or send false commands to the remote units. Moreover, experts are concerned that terrorists could, for example, trigger a cyber attack to release harmful amounts of water treatment chemicals, such as chlorine, into the public's drinking water.

Cyber Attacks on Control Systems Have Been Reported

Experts in control systems have verified numerous incidents that have affected control systems. Reported attacks include the following:

- In 1994, the computer system of the Salt River Project, a major water and electricity provider in Phoenix, Arizona, was breached.
- In March 1997, a teenager in Worcester, Massachusetts, remotely disabled part of the public switching network, disrupting telephone service for 600 residents and the fire department and causing a malfunction at the local airport.
- In the spring of 2000, a former employee of an Australian company that develops manufacturing software applied for a job with the local government, but was rejected. Over a 2-month period, the disgruntled rejected employee reportedly used a radio transmitter on as many as 46 occasions to remotely hack into the controls of a sewage treatment system and ultimately release about 264,000 gallons of raw sewage into nearby rivers and parks.
- In the spring of 2001, hackers mounted an attack on systems that were part of a development network at the California Independent System Operator, a facility that is integral to the movement of electricity throughout the state.
- In August 2003, the Nuclear Regulatory Commission confirmed that in January 2003, the Microsoft SQL Server worm—otherwise known as Slammer—infected a private computer network at the Davis-Besse nuclear power plant in Oak Harbor, Ohio, disabling a safety monitoring system for nearly 5 hours. In addition, the plant's process computer failed, and it took about 6 hours for it to become available again. Slammer reportedly also affected communications on the control networks of at least five other utilities by propagating so quickly that control system traffic was blocked.

In addition, in 1997, the Department of Defense (DOD) undertook the first systematic exercise to determine the nation's and DOD's vulnerability to cyberwar. During a 2-week military exercise known as Eligible Receiver, staff from NSA used widely available tools to show how to penetrate the control systems that are associated with providers of electric power to DOD installations. Other assessments of control systems at DOD

installations have demonstrated vulnerabilities and identified risks in the installations' network and operations.

Securing Control Systems Poses Significant Challenges

The control systems community faces several challenges to securing control systems against cyber threats. These challenges include (1) the limitations of current security technologies in securing control systems, (2) the perception that securing control systems may not be economically justifiable, and (3) the conflicting priorities within organizations regarding the security of control systems.

Lack of Specialized Security Technologies for Control Systems

According to industry experts, existing security technologies, as well as strong user authentication and patch management practices, are generally not implemented in control systems because control systems usually have limited processing capabilities, operate in real time, and are typically not designed with cybersecurity in mind.

Existing security technologies[13] such as authorization, authentication, encryption, intrusion detection, and filtering of network traffic and communications, require more bandwidth, processing power, and memory than control system components typically have. Controller stations are generally designed to do specific tasks, and they often use low-cost, resource-constrained microprocessors. In fact, some control system devices still use the Intel 8088 processor, which was introduced in 1978. Consequently, it is difficult to install current security technologies without seriously degrading the performance of the control system.

For example, complex passwords and other strong password practices are not always used to prevent unauthorized access to control systems, in part because this could hinder a rapid response to safety procedures during an emergency. As a result, according to experts, weak passwords that are easy to guess, shared, and infrequently changed are reportedly common in control systems, including the use of default passwords or even no password at all.

[13] See U.S. General Accounting Office, *Information Security: Technologies to Secure Federal Systems*, GAO-04-467 (Washington, D.C.: March 9, 2004) for a discussion of cybersecurity technologies.

In addition, although modern control systems are based on standard operating systems, they are typically customized to support control system applications. Consequently, vendor-provided software patches may be either incompatible with the customized version of the operating system or difficult to implement without compromising service by shutting down "always-on" systems or affecting interdependent operations. Another constraint on deploying patches is that support agreements with control system vendors often require the vendor's approval before the user can install patches. If a patch is installed in violation of the support agreement, the vendor will not take responsibility for potential impacts on the operations of the system. Moreover, because a control system vendor often requires that it be the sole provider of patches, if the vendor delays in providing patches, systems remain vulnerable without recourse.

Information security organizations have noted that a gap exists between currently available security technologies and the need for additional research and development to secure control systems. Research and development in a wide range of areas could lead to more effective technologies. For example, although technologies such as robust firewalls and strong authentication can be employed to better segment control systems from external networks, research and development could help to address the application of security technologies to the control systems themselves. Other areas that have been noted for possible research and development include identifying the types of security technologies needed for different control system applications, determining acceptable performance trade-offs, and recognizing attack patterns for use in intrusion detection systems.

Industry experts have identified challenges in migrating system components to newer technologies while maintaining uninterrupted operations. Upgrading all the components of a control system can be a lengthy process, and the enhanced security features of newly installed technologies—such as their ability to interpret encrypted messages—may not be able to be fully utilized until all devices in the system have been replaced and the upgrade is complete.

Securing Control Systems May Not Be Perceived as Economically Justifiable

Experts and industry representatives have indicated that organizations may be reluctant to spend more money to secure control systems. Hardening the security of control systems would require industries to expend more resources, including acquiring more personnel, providing

training for personnel, and potentially prematurely replacing current systems, which typically have a lifespan of about 20 years.

Several vendors suggested that since there have been no reports of significant disruptions caused by cyber attacks on U.S. control systems, industry representatives believe the threat of such an attack is low. While incidents have occurred, to date there is no formalized process for collecting and analyzing information about control systems incidents, thus further contributing to the skepticism of control systems vendors. We have previously recommended that the government work with the private sector to improve the quality and quantity of information being shared among industries and government about attacks on the nation's critical infrastructures.[14]

Until industry users of control systems have a business case to justify why additional security is needed, there may be little market incentive for the private sector to develop and implement more secure control systems. We have previously reported that consideration of further federal government efforts is needed to provide appropriate incentives for nonfederal entities to enhance their efforts to implement CIP—including protection of control systems. Without appropriate consideration of public policy tools, such as regulation, grants, and tax incentives, private-sector participation in sector-related CIP efforts may not reach its full potential.[15]

Organizational Priorities Conflict

Finally, several experts and industry representatives indicated that the responsibility for securing control systems typically includes two separate groups: (1) IT security personnel and (2) control system engineers and operators. IT security personnel tend to focus on securing enterprise systems, while control system engineers and operators tend to be more concerned with the reliable performance of their control systems. These experts indicate that, as a result, those two groups do not always fully understand each other's requirements and so may not effectively collaborate to implement secure control systems.

[14]U.S. General Accounting Office, *Critical Infrastructure Protection: Challenges for Selected Agencies and Industry Sectors*, GAO-03-233 (Washington, D.C.: Feb. 28, 2003).

[15]U.S. General Accounting Office, *Homeland Security: Information Sharing Responsibilities, Challenges, and Key Management Issues*, GAO-03-1165T (Washington, D.C.: Sept. 17, 2003).

These conflicting priorities may perpetuate a lack of awareness of IT security strategies that could be deployed to mitigate the vulnerabilities of control systems without affecting their performance. Although research and development will be necessary to develop technologies to secure individual control system devices, existing IT security technologies and approaches could be implemented as part of a secure enterprise architecture to protect the perimeters of, and access to, control system networks. Existing IT security technologies include firewalls, intrusion-detection systems, encryption, authentication, and authorization. Approaches to IT security include segmenting control system networks and testing continuity plans to ensure safe and continued operation.

To reduce the vulnerabilities of its control system, officials from one company formed a team composed of IT staff, process control engineers, and manufacturing employees. This team worked collaboratively to research vulnerabilities and to test fixes and workarounds.

Efforts to Strengthen the Cybersecurity of Control Systems Under Way, but Lack Adequate Coordination

Government, academia, and private industry have independently initiated multiple efforts and programs focused on some of the key areas that should be addressed to strengthen the cybersecurity of control systems. Our March 2004 report includes a detailed discussion of many initiatives. The key areas—and illustrative examples of ongoing efforts in these areas—include the following:

- **Research and development of new security technologies to protect control systems**. Both federal and nonfederal entities have initiated efforts to develop encryption methods for securing communications on control system networks and field devices. Moreover, DOE is planning to establish a National SCADA Test Bed to test control system vulnerabilities. However, funding constraints have delayed the implementation of the initial phases of these plans.
- **Development of requirements and standards for control system security**. Several entities are working to develop standards that increase the security of control systems. The North American Electric Reliability Council (NERC) is preparing to draft a standard that will include security requirements for control systems. In addition, the Process Controls Security Requirements Forum (PCSRF), established by NIST and NSA, is working to define a common set of information security requirements for

control systems. However, according to NIST officials, reductions to fiscal year 2004 appropriations will delay these efforts.

- **Increased awareness of security and sharing of information about the implementation of more secure architectures and existing security technologies**. To promote awareness of control system vulnerabilities, DOE has created security programs, trained teams to conduct security reviews, and developed cybersecurity courses. The Instrumentation Systems and Automation Society has reported on the known state of the art of cybersecurity technologies as they are applied to the control systems environment, to clearly define what technologies can currently be deployed.
- **Implementation of effective security management programs, including policies and guidance that consider control system security**. Both federal and nonfederal entities have developed guidance to mitigate the security vulnerabilities of control systems. DOE's *21 Steps to Improve Cyber Security of SCADA Networks* provides guidance for improving the security of control systems and establishing underlying management processes and policies to help organizations improve the security of control system networks.

In previous reports, we have recommended the development of a comprehensive and coordinated national plan to facilitate the federal government's CIP efforts. This plan should clearly delineate the roles and responsibilities of federal and nonfederal CIP entities, define interim objectives and milestones, set time frames for achieving objectives, and establish performance measures.

The President in his homeland security strategies and Congress in enacting the Homeland Security Act designated DHS as responsible for developing a comprehensive national infrastructure plan. The plan is expected to inform DHS on budgeting and planning for CIP activities and on how to use policy instruments to coordinate among government and private entities to raise the security of our national infrastructures to appropriate levels. According to Homeland Security Presidential Directive 7 (HSPD 7), issued December 17, 2003, DHS is to develop this formalized plan by December 2004.

In February 2003, the President's *National Strategy to Secure Cyberspace* established a role for DHS to coordinate with other government agencies and the private sector to improve the cybersecurity of control systems. DHS's assigned role includes:

- ensuring that there is broad awareness of the vulnerabilities in control systems and the consequences of exploiting these vulnerabilities,
- developing best practices and new technologies to strengthen the security of control systems, and
- identifying the nation's most critical control system sites and developing a prioritized plan for ensuring cyber security at those sites.

In addition, the President's strategy recommends that DHS work with the private sector to promote voluntary standards efforts and the creation of security policy for control systems.

DHS recently began to focus on the range of activities that are under way among the numerous entities that are working to address these areas. In October 2003, DHS's Science and Technology Directorate initiated a study to determine the current state of security of control systems. In December 2003, DHS established the Control Systems Section within the Protective Security Division of its Information Analysis and Infrastructure Protection (IAIP) Directorate. The objectives of this section are to identify computer-controlled systems that are vital to infrastructure functions, evaluate the potential threats to these systems, and develop strategies that mitigate the consequences of attacks. In addition, IAIP's National Cyber Security Division (NCSD) is planning to develop a methodology for conducting cyber assessments across all critical infrastructures, including control systems. The objectives of this effort include defining specific goals for the assessments and, based on their results, developing sector-specific recommendations to mitigate vulnerabilities. NCSD also plans to examine processes, technology, and available policy, procedures, and guidance. Because these efforts have only recently been initiated, DHS acknowledges that it has not yet developed a strategy for implementing the functions mentioned above.

As I previously mentioned, many government and nongovernment entities are spearheading various initiatives to address the challenge of implementing cybersecurity for the vital systems that operate our nation's critical infrastructures. While some coordination is occurring, both federal and nonfederal control systems experts have expressed their concern that these efforts are not being adequately coordinated among government agencies, the private sector, and standards-setting bodies. DHS's coordination of these efforts could accelerate the development and implementation of more secure systems to manage our critical infrastructures. In contrast, insufficient coordination could contribute to

- delays in the general acceptance of security requirements and the adoption of successful practices for control systems,
- failure to address gaps in the research and development of technologies to better secure control systems,
- impediments to standards-creating efforts across industries that could lead to less expensive technological solutions, and
- reduced opportunities for efficiency that could be gained by leveraging ongoing work.

In summary, it is clear that the systems that monitor and control the sensitive processes and physical functions of the nation's critical infrastructures are at increasing risk from threats of cyber attacks. Securing these systems poses significant challenges. Numerous federal agencies, critical infrastructure sectors, and standards-creating bodies are leading various initiatives to address these challenges. DHS's implementation of our recommendation—with which the department concurred—to develop and implement a strategy for better coordinating the cybersecurity of our critical infrastructures' control systems among government and private sector entities can accelerate progress in securing these critical systems. Additionally, implementing existing IT technologies and security approaches can strengthen the security of control systems. These approaches include establishing an effective security management program, building successive layers of defense mechanisms at strategic access points to the control system network, and developing and testing continuity plans to ensure safe operation in the event of a power outage or cyber attack.

Mr. Chairman, this concludes my statement. I would be pleased to answer any questions that you or other members of the Subcommittee may have at this time.

If you should have any questions about this statement, please contact me at (202) 512-3317 or Elizabeth Johnston, Assistant Director, at (202) 512-6345. We can also be reached by e-mail at daceyr@gao.gov and johnstone@gao.gov, respectively.

Other individuals who made key contributors to this testimony include Shannin Addison, Joanne Fiorino, Alison Jacobs, Anjalique Lawrence, and Tracy Pierson.

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