Chapter 3 of:

Industrial Automation and Control System Security Principles:

Protecting the Critical Infrastructure, Second Edition

Ronald L. Krutz, PhD, PE

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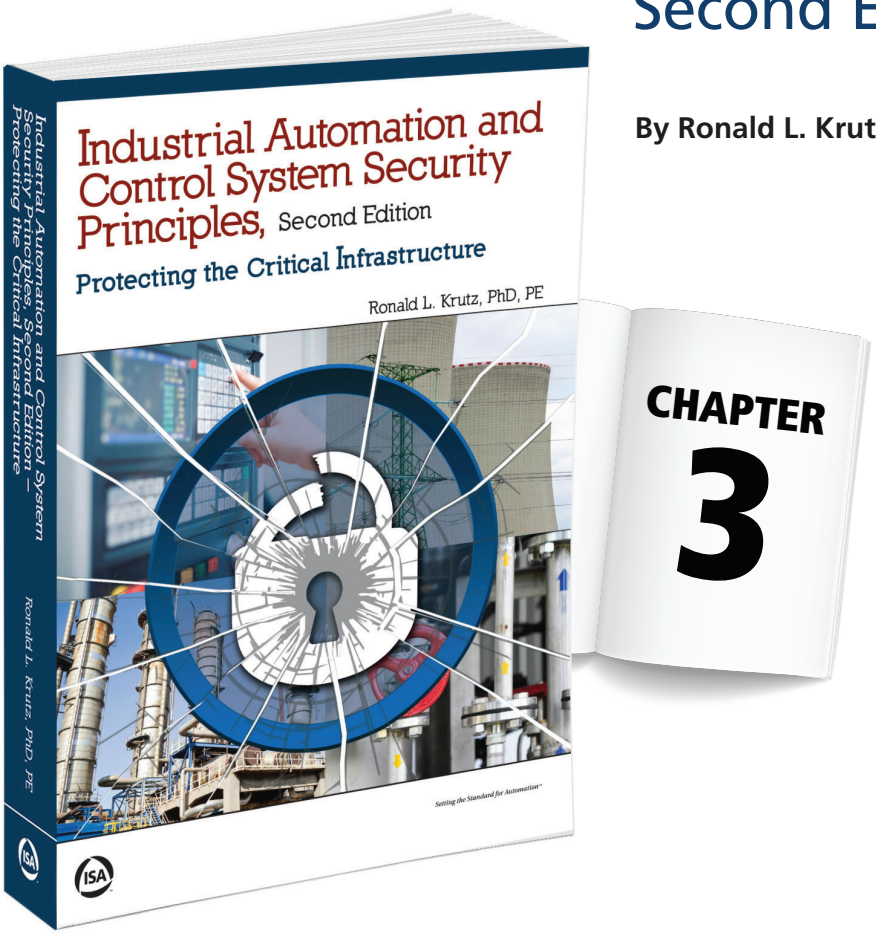

By Ronald L. Krutz, PhD, PE

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Industrial Automation and Control System Culture versus IT Paradigms

Some of the basic principles of information system security were presented in Chapter 2 as a prelude to selectively and properly applying them to securing industrial automation and control systems. As a prerequisite to this adaptation, it is important to examine the differences in culture, requirements, and operational issues between automation and control systems and IT systems. Critical areas that have to be addressed include safety, real-time demands, maintenance, productivity, training, and personnel mindsets. These topics and related subject areas are discussed in this chapter to help the reader better understand how to apply security principles to automation and control systems without negatively impacting their primary mission and in full acknowledgement of their special requirements.

Differences in Culture, Philosophy, and Requirements

The major advances in securing computer systems and networks have come through the information system technology route, with origins in computer science and software engineering. The principal players are IT system administrators, systems analysts, database administrators, software engineers, network administrators, chief information officers (CIOs), and so on. On the other hand, a large number of the personnel populating the industrial automation and control system field come from engineering backgrounds, with training in such areas as electrical engineering, chemical engineering, mechanical engineering, systems engineering, and control engineering.

The motivation, requirements, and focus of each of the groups are, in many instances, largely divergent, with some overlapping common areas. For example, software quality and process improvement methods widely used in the IT environment are often foreign to control engineers and in fact may be viewed as cumbersome in implementing SCADA and process control algorithms. In addition, the performance of a process in a plant is critical, and inadequate performance in production areas can result in huge financial losses, equipment damage, and personnel injuries. These severe consequences of operational errors are not usually a common occurrence in IT facilities. Similarly, safety is a critical concern in a production environment, and control system malfunctions can result in fires or explosions in some instances. Thus, in a production environment, safety and performance usually take precedence over information security, which is not the case in an IT system.

Some of the major differences between IT and industrial automation and control system requirements are listed in Table 3-1.

Table 3-1. Comparison between IT and Industrial Control and Automation Systems Issues

Issue	IT Systems	Industrial Automation and Control Systems
Application of encryption	Advanced encryption systems used.	Encryption used sometimes or not at all. Delays caused by encryption software are a consideration.
Degree of employment of patch management	Implementation of software patches performed routinely under formal procedures.	Installation of software patches usually done infrequently, with deliberation, and with involvement of vendors. The impact of software patches should be tested off-line to ensure no harmful effects are introduced into the process or plant. In some instances, adding patches can produce some dangerous consequences.
Degree of vulnerability testing	Penetration testing by ethical hackers is widely used to expose vulnerabilities.	Penetration testing must be conducted sparingly and at appropriate times in order not to inadvertently cause malfunctions in monitoring and control systems.

Table 3-1. Comparison between IT and Industrial Control and Automation Systems Issues

Employment and impact of security software	Antivirus software is effective and commonly used to scan for malware.	Antivirus software can be used but issues, such as delays due to scanning and processing and lack of spare computing cycles, might cause problems in plant systems.
Employment of change management	Change management is used extensively to document and confirm system changes.	Change management is employed inconsistently and sporadically in many organizations. Changes might also result in hazardous situations.
Impact of equipment upgrades	Equipment modifications, upgrades, and replacements occur almost continuously in various parts of organizations.	Many legacy systems in use with few changes over periods of many years.
Level of security awareness training	Awareness training is actively conducted in accordance with security policy.	Security awareness training is conducted sporadically and inconsistently in many cases.
Tolerance to data loss	Recovery from data loss can usually be accomplished from backups without severe consequences in most situations.	Loss of data can result in loss of product, unsafe conditions, and disruption of plant operations.
Tolerance to loss of availability	Recovery follows standard procedures and unless availability is lost for extended periods of time, effects are not disastrous. However, availability is critical and can affect mission objectives.	Systems should be designed with resiliency; however many are not, particularly legacy systems. Loss of availability can have serious consequences, including safety of personnel and equipment.
Tolerance to loss of confidentiality	Depending on the data involved, the consequences might be minimal or extremely harmful, such as the loss of trade secrets, personnel data, credit card numbers, and health information.	Consequences not usually severe.
Tolerance to loss of integrity	Consequences can range from minimal to extremely harmful if critical data has been altered and is acted on as being valid.	Consequences can be very severe because, in many instances, critical decisions are made based on data assumed to be correct.

Table 3-1. Comparison between IT and Industrial Control and Automation Systems Issues

Tolerance to system delays	In most cases, delays might be considered a nuisance, but can be tolerated.	In situations where critical control decisions are based on deterministic response times, delays might result in serious or dangerous consequences.
Use of auditing	Based on organizational polices, internal and external audits are normally conducted and provide detective controls for breaches of information system security.	Audits of a systems' security posture are conducted irregularly and are a function of the particular organization and regulatory requirements.
System performance	Performance can be suboptimal at times.	Proper performance is critical.
Safety	Safety is critical, particularly that of personnel.	Safety is critical, particularly that of personnel.

Figure 3-1 summarizes the important issues listed in Table 3-1 and emphasizes some of the common areas between IT and automation and control systems.

The lesson to be learned from these comparisons is that traditional information system security knowledge and methods provide a solid basis for addressing industrial automation and control system security, albeit with deliberate, appropriate, and intelligent modifications required to address the unique characteristics of automation and control systems.

One important starting point in incorporating these modifications is education. In general, most universities and certification programs addressing computer and network security have been heavily focused on IT security. Automation and control systems, which are typically sitting on isolated networks and are relatively few in number compared to IT systems, have not been considered to be interesting targets. With the advent of the terrorism threat, this situation is no longer the case. In addition, SCADA and plant process control systems are now being connected to large networks and the Internet.

The Certified Information System Security Professional (CISSP) and related certifications do not address the security of industrial automation and control

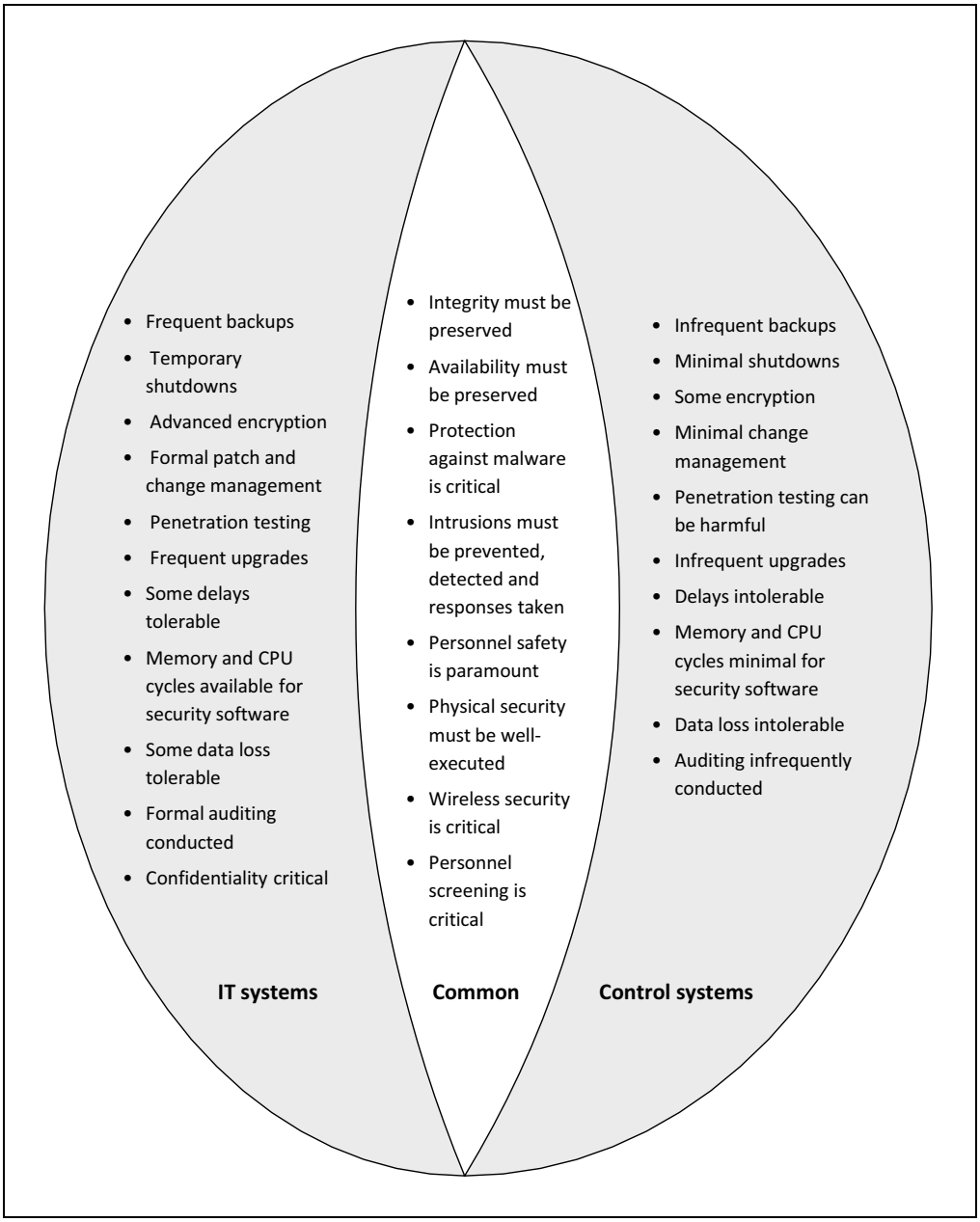

Figure 3-1. IT and Automation and Control System Issue Comparisons

systems. Organizations, such as ISA, have addressed this problem and are filling a critical need. NIST has generated special publications that directly address industrial automation and control systems. However, it is important that security training related to the control of production lines, industrial processes, electrical transmission and distribution, pipelines, chemical

plants, and so on moves to the fore in universities, technical institutes, and certification organizations.

To understand how to adapt IT security methods to industrial automation and control system security, threats to the latter have to be identified and understood. One impediment to full disclosure of threats realized is the fact that a majority of affected facilities are privately owned, and these organizations are reluctant to publicize security breaches that could negatively affect their reputation and value.

Organizations also need incentives to invest in upgrading their automation and control infrastructure. Many existing installations have been in place for 10 or 20 years, and investments in security have to compete with other compelling initiatives in an organization.

Considerations in Adapting IT Security Methods to Industrial Automation and Control Systems

In order to secure an IACS, there are specific issues that have to be addressed that take into account the differences between IT systems and IACSs. These issues include the following:

- Accountability, authorization, and computer forensics have not matured and have not been implemented widely in IACSs as compared to IT systems.
- Ethernet to serial line paths provide a means of injecting malicious commands into a control network.
- Excessive checking, encryption, monitoring, and so on can interfere with the deterministic nature of process control systems.
- In many IACS environments, control engineers have multiple responsibilities that, in many instances, violate the security principle of separation of duties.
- Installing patches and upgrades in process control systems can lead to serious and sometimes dangerous situations in production facilities.
- Life-cycle design disciplines common in the IT field are not widely used in industrial automation and control systems.

- Maintenance hooks and trap doors installed in automation and control systems for remote maintenance can be easy entry points to modify critical software and firmware with negative consequences.
- Many IACS vendors combine safety mechanisms with security mechanisms, leading to single points of failure and less resiliency than separating these two functions logically and physically.
- Many manufacturing facilities and SCADA installations house legacy systems with outdated technology, minimal memory and computing power, and little thought to security.
- Port scanning of automation and control systems can result in blockages and lack of system availability.
- Remote access into automation and control systems via older modems or newer wireless devices poses a serious threat to security.
- There is a trend to apply protocols used for IT systems to industrial control and automation systems because of their wide availability, their lower cost, and the existence of trained personnel. However, in most instances, these protocols were not designed for deterministic process control systems, and they are vulnerable to many existing attacks.
- There is heavy reliance on suppliers who provide modified software and hardware for IACSs, resulting in nonstandard implementations that are difficult to maintain without support from these suppliers.
- Weak authentication mechanisms in many SCADA systems and networked plant control systems leave them vulnerable to attack.

A variety of additional items must be considered when discussing comparisons between IT and industrial automation and control systems. The concepts related to risk management and the means to protect industrial automation and control systems will be discussed in detail in Chapters 5 and 6, respectively. However, it is important to now examine some related critical subject areas to provide a basis for developing more specific security solutions.

Threats

Threats to IT and industrial automation and control systems come from different sources, with different motivations. It is important to understand these

threat sources and their characteristics in order to counter any malicious activities on their part. NIST SP 800-30[1] summarizes the various types of threat sources and some of their driving factors, as shown in Table 3-2. Table 3-3, also from NIST SP 800-30, provides a listing of some general threat sources, including environmental ones, which can also cause disruptions to industrial automation and control systems.

The categories of terrorists, industrial espionage, and insiders are of particular interest in connection with industrial automation and control systems. Traditionally, insider threats have been considered one of the most dangerous because they give insiders the ability to bypass protective measures. However, external threats are increasing and are also of grave concern, particularly relating to our nation's critical infrastructure and resource processing plants. In addition, threats to automation systems can materialize from environmental and structural sources, as illustrated in the next section.

Sensitivity of Industrial Automation and Control Systems to Upgrades and Modifications

One area that is not usually considered when discussing the relative sensitivities of IT systems and industrial automation and control systems is the effects of equipment upgrades and modifications. A particularly relevant example concerns the consequences of converting analog controls to digital controls. Digital systems transfer information via pulses, which inherently generate high frequency electromagnetic radiation that can interfere with control system operations. An article in the journal *Interference Technology*[2] describes the electromagnetic radiation emission environment in a nuclear plant that was being changed from analog to digital controls. The authors obtained measurement data in the range of 100 Hz to 6 GHz in instances before and after the conversion.

Table 3-2. Threats and Motivations for Attackers

Source: NIST SP 800-30 (2012)

Threat-Source	Motivation	Threat Actions
Hacker, cracker	Challenge Ego Rebellion	• Hacking • Social engineering • System intrusion, break-ins • Unauthorized system access
Computer criminal	Destruction of information Illegal information disclosure Monetary gain Unauthorized data alteration	• Computer crime (e.g., cyber stalking) • Fraudulent act (e.g., replay, impersonation, interception) • Information bribery • Spoofing • System intrusion
Terrorist	Blackmail Destruction Exploitation Revenge	• Bomb/terrorism • Information warfare • System attack (e.g., distributed denial of service) • System penetration • System tampering
Industrial espionage (companies, foreign governments, other government interests)	Competitive advantage Economic espionage	• Economic exploitation • Information theft • Intrusion on personal privacy • Social engineering • System penetration • Unauthorized system access (access to classified, proprietary, and/or technology-related information)
Insiders (poorly trained, disgruntled, malicious, negligent, dishonest, or terminated employees)	Curiosity Ego Intelligence Monetary gain Revenge Unintentional errors and omissions (e.g., data entry error, programming error)	• Assault on an employee • Blackmail • Browsing of proprietary information • Computer abuse • Fraud and theft • Information bribery • Input of falsified, computed data • Interception • Malicious code (e.g., virus, logic bomb, Trojan horse) • Sale of personal information • System bugs • System intrusion • System sabotage • Unauthorized system access

The testing followed guidelines in U.S. Nuclear Regulatory Commission Regulatory Guide, NUREG 1.180,[3] and Electric Power Research Institute (EPRI) document TR-102023-2004.[4] In the tests, antennas were installed next to three cabinets housing control electronics, and radiation emission measurements were taken from the analog and digital control installations. Some of the results obtained are summarized in Table 3-4, showing frequencies at which peak amplitudes occur at antennas 1 and 2.

Table 3-3. Listing of General Threat Sources

Source: NIST SP 800-30 (2012)

Type of Threat Source	Description	Characteristics
Adversarial • Individual • Outsider • Insider • Trusted insider • Privileged insider • Group • Ad hoc • Established • Organization • Nation-state	Individuals, groups, organizations, or states that seek to exploit the organization's dependence on cyber resources (i.e., information in electronic form, information and communications technologies, and the communications and information-handling capabilities provided by those technologies).	Capability, intent, targeting
Accidental • Ordinary user • Privileged user/ administrator	Erroneous actions taken by individuals in the course of executing their everyday responsibilities.	Range of effects
Structural • IT Equipment • Storage • Processing • Communications • Display • Sensor • Controller • Environmental controls • Temperature/humidity controls • Power supply • Software • Operating system • Networking • General-purpose application • Mission-specific application	Failures of equipment, environmental controls, or software due to aging, resource depletion, or other circumstances that exceed expected operating parameters.	Range of effects

Table 3-3. Listing of General Threat Sources

Source: NIST SP 800-30 (2012)

Environmental • Natural or man-made disaster • Fire • Flood/tsunami • Windstorm/tornado • Hurricane • Earthquake • Bombing • Overrun • Unusual natural event (e.g., sunspots) • Infrastructure failure/outage • Telecommunications • Electrical power	Natural disasters and failures of critical infrastructures on which the organization depends, but which are outside the control of the organization. NOTE: Natural and man-made disasters can also be characterized in terms of their severity and/or duration. However, because the threat source and the threat event are strongly identified, severity and duration can be included in the description of the threat event (e.g., Category 5 hurricane causes extensive damage to the facilities housing mission-critical systems, making those systems unavailable for three weeks).	Range of effects

Table 3-4. Radiation Emission Measurements

Source: Keebler and Berger (2011)

Antenna	Analog Measurement		Digital Measurement	
	Frequency	Significant Peak Amplitudes (dBμV/m)	Frequency	Significant Peak Amplitudes (dBμV/m)
1	1.34 MHz	99.2	468 MHz	71.6
1	928 MHz	76.6	826 MHz	94.5
1			928 MHz	113.5
1			1.35 GHz	49.9
1			1.88 GHz	50.5
1			1.92 GHz	53.4
1			2.41 GHz	76.3
1			2.46 GHz	54.4
1			5.82 GHz	60.6
2	1.04 MHz	99.3	2 MHz	84
2	4.55 MHz	88.5	10 MHz	80
2			1 GHz	109
2			1.17 GHz	48.8
2			1.92 GHz	48.9
2			2.42 GHz	57.7
2			5.82 GHz	50.9

This data is plotted in Figures 3-2 and 3-3 for antennas 1 and 2, respectively. Note that the digital electronics generate more peak radiation generally and more at high frequencies compared to the analog equipment. These peak emissions have the potential to interfere with control system signals and cause malfunctions if proper shielding and isolation are not applied.

The sample electromagnetic emanations collected illustrate the necessity to ensure electromagnetic compliance (EMC) when equipment upgrades are made to plant control systems. These actions will serve to protect against interruptions of control systems' operation due to electromagnetic emissions from digital systems.

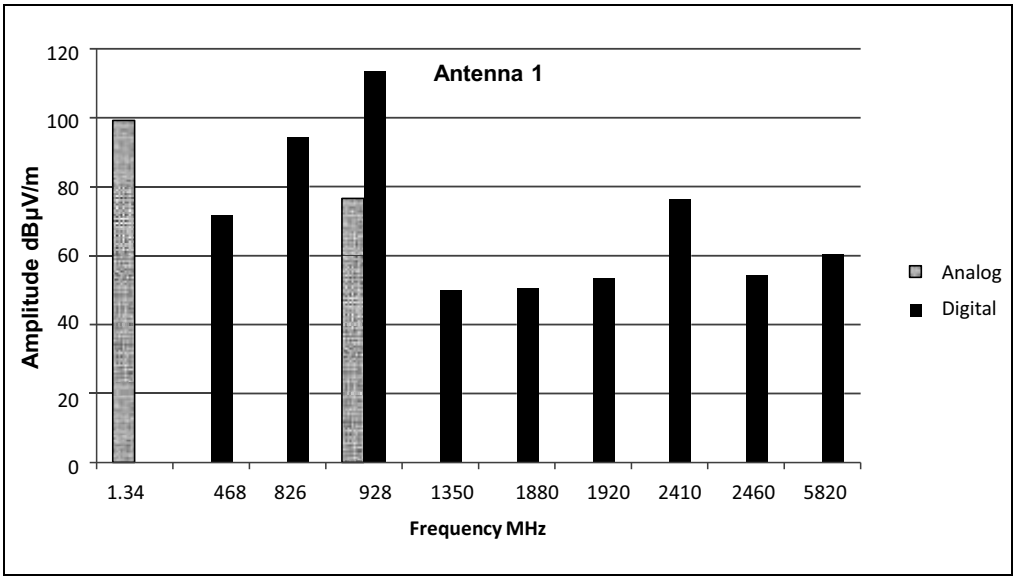

Figure 3-2. Analog and Digital Radiation Emissions Received at Antenna 1

IT and Industrial Automation and Control Systems Comparisons from a Standards Perspective

Valuable insight into the contrasts and similarities between IT systems security focus areas and those of industrial automation and control systems can be obtained from an example using standards that represent each of the areas. In this example, ISO/IEC 27002, *Code of Practice for Information Security Management,*[5] will be used to represent IT systems security areas of emphasis while ANSI/ISA-62443-2-1 (99.02.01)-2009, *Security for Industrial Automation and Control Systems Part 2-1: Establishing an Industrial Automation and Control Systems*

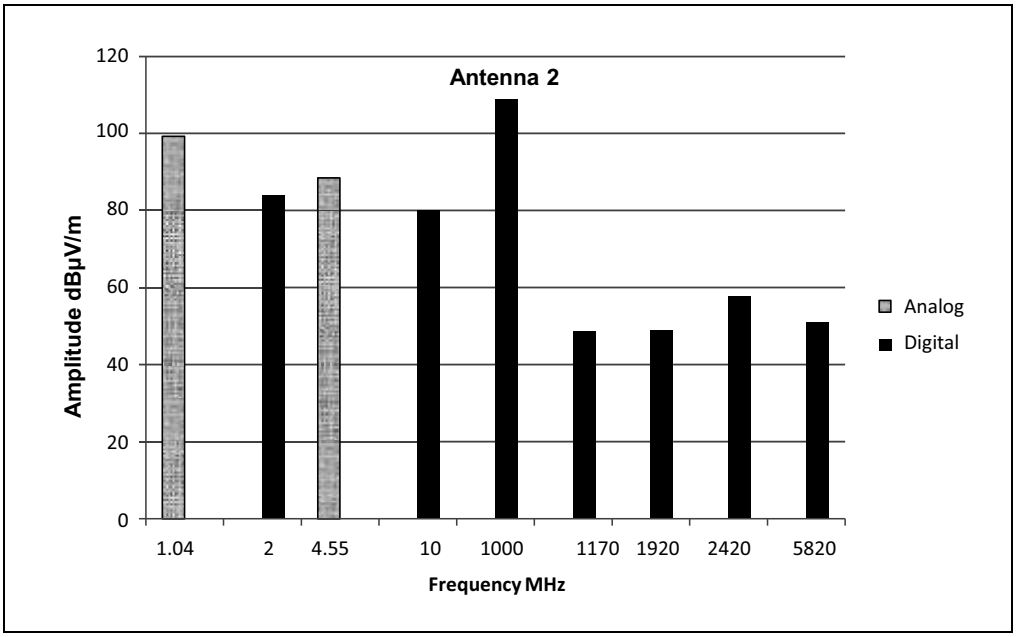

Figure 3-3. Analog and Digital Radiation Emissions Received at Antenna 2

Security Program,[6] will be used to illustrate the major concerns of automation and control system security.

In each document, there are common areas addressed by both standards and other areas addressed by one standard and not the other. Figure 3-4 summarizes the main characteristics of each standard and identifies common areas addressed by both, as well as topics that are addressed mainly by one document and not the other.

Figure 3-4 shows that topics, such as change management, email security, access control policies, digital signatures, compliance, and business continuity planning are among the areas considered critical for IT systems that are not emphasized in automation and control system standards. Conversely, for automation and control systems, the significant domains not covered include security architecture analysis, quantitative and qualitative analysis, information security management, and information security testing. Areas of common emphasis include information security policy, risk assessment, training, media physical security, remote access, event logging, and protection against malware.

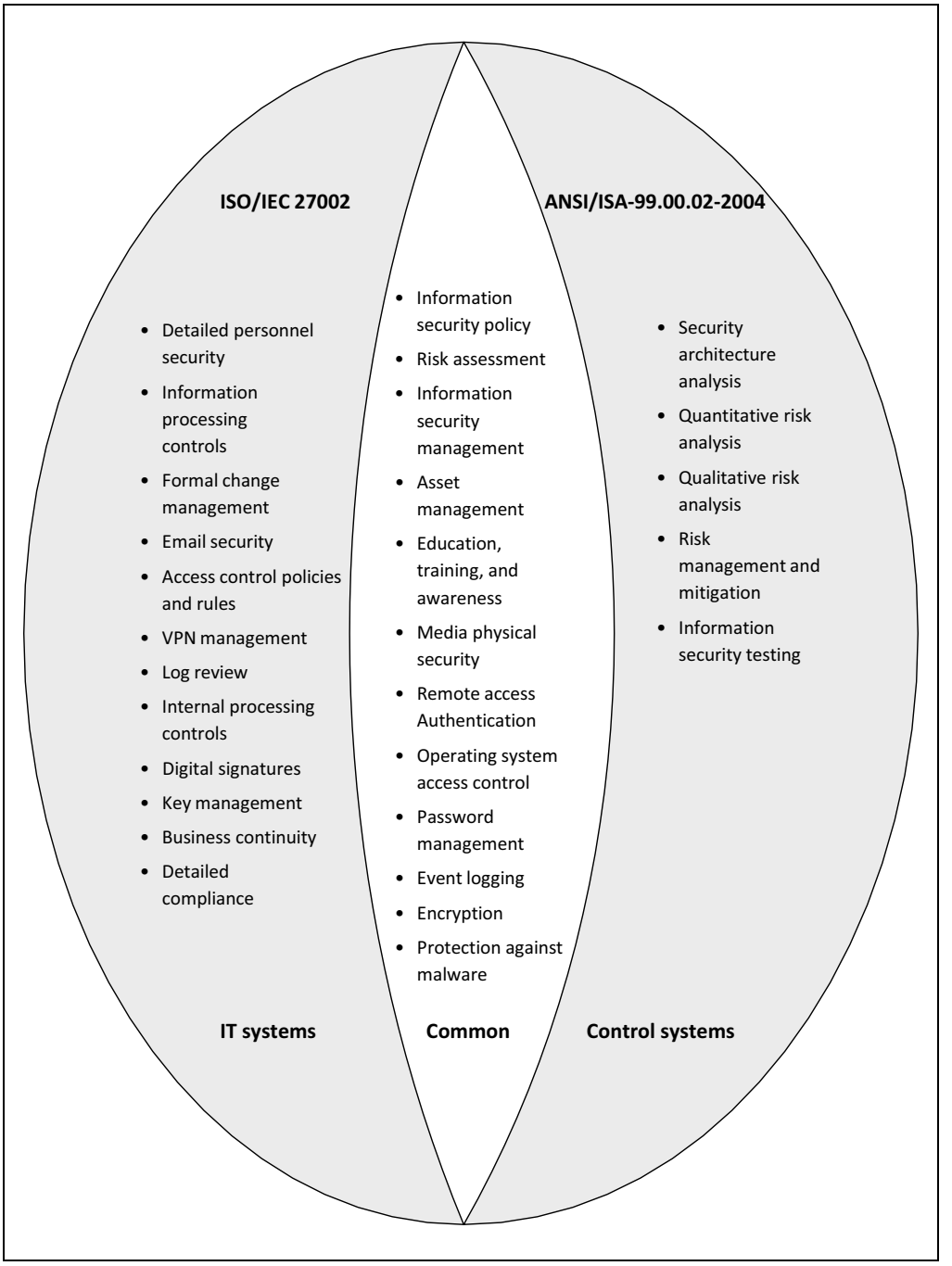

Figure 3-4. Standards Comparison Example of IT versus IACSs Important Security

Summary

Understanding the requirements of industrial automation and control systems security and how they relate to IT systems requires a mapping of these requirements onto the emerging technologies being employed in the control of production processes, as well as the critical infrastructure (represented primarily by the electrical generation and distribution grid). The advances in capability and sophistication of industrial automation and control systems require a tailored approach to security. Some of the factors pushing the industrial automation and control systems security envelope include:

- The Smart Grid
- Advanced cryptography and key management applications
- Advanced PLCs and PACs
- Advanced protective relaying
- Advanced wireless networks
- Alarm processing
- Availability of real-time energy information
- Multisphere security among IT, transportation, and power systems
- Redundancy in networks, equipment, and sensors
- Fiber communication
- Use of GPS tracking

Chapter 4 will investigate the technical evolution taking place in elements of the critical infrastructure and in key production facilities to identify the important risk factors and areas of maximum potential impact in the event of an attack.

Review Questions for Chapter 3

3.1 Which of the following statements is generally TRUE regarding an industrial automation and control system?

A. Installation of software patches can be performed routinely and frequently.

B. Encryption of data can sometimes lead to problematic delays.

C. Penetration testing can be conducted routinely and frequently.

D. Confidentiality is a key concern in automation systems as opposed to integrity and availability.

3.2 In both IT and automation and control systems, which of the following is the primary concern in the event of an emergency or malicious event?

A. Equipment safety

B. Preservation of documentation

C. Personnel safety

D. Facility protection

3.3 Which of the following statements is FALSE?

A. Flash drives and other portable memory devices can be sources of malware injections into control systems.

B. Maintenance hooks and trap doors installed in automation and control systems for remote maintenance can be easy entry points to modify critical software and firmware with negative consequences.

C. In many control system environments, control engineers, in general, do not have multiple responsibilities, such that the security principle of separation of duties is not normally violated.

D. Many facilities house legacy systems with outdated technology, minimal memory and computing power, and little thought to security.

3.4 Which of the following actions is the most likely to result in blockages and lack of system availability in automation and control systems?

A. Remote access

B. Life-cycle design

C. Accountability

D. Port scanning

3.5 Which threat source is motivated by revenge, ego, and dissatisfaction?

A. Insider

B. Espionage

C. Criminal

D. Hacker

3.6 What is a source of a possible disruption of control system functions that is not normally considered?

A. Changes from digital to analog systems

B. Upgrades from analog to digital systems

C. Malware

D. Attacks

3.7 In general, what distinguishes analog control equipment from digital control equipment?

A. Analog controls generate more high-frequency peak voltages than digital controls.

B. Digital controls generate more high-frequency peak voltages than analog controls.

C. Analog controls generate essentially the same number of high-frequency peak voltages as digital controls.

D. Digital controls generate essentially the same number of high-frequency peak voltages as analog controls.

3.8 Which of the following is more likely to be performed in an IT environment than in an automation and control system environment?

A. Security architecture analysis

B. Information security testing

C. Quantitative risk analysis

D. Change management

3.9 Which of the following is more likely to be performed in an IT environment than in an automation and control system environment?

A. Security architecture analysis

B. Information security testing

C. Quantitative risk analysis

D. Change management

3.10 Which of the following threat sources is motivated by economic exploitation and competitive advantage, and uses social engineering?

A. Insider

B. Terrorist

C. Industrial espionage

D. Computer criminal

3.11 What is a detective control that is more frequently applied in IT systems than in control and automation systems?

A. Firewall

B. Separation of duties

C. Biometrics

D. Auditing

3.12 Which of the following is NOT a usual reason for an organization's reluctance to disclose successful attacks against it?

A. Hope the attack will harm competitors

B. Embarrassment

C. Effect on reputation

D. Possible loss of customers

3.13 Which of the following can lead to a single point of failure in an industrial automation and control system?

A. Separation of duties

B. Disk redundancy

C. Combination of safety and security mechanisms

D. Use of authentication with identification

3.14 What is a typical characteristic of industrial automation and control systems?

A. Have excess computing cycles

B. Have limited extra computing cycles

C. Have excess memory

D. Computational speed is not an issue

3.15 What is a typical characteristic of an automation and control system supplier?

A. Usually ensures maintenance hooks are never left enabled without the customer's approval

B. Usually ensures default passwords are never duplicated from one customer to another

C. Usually provides unmodified off-the-shelf hardware and software

D. Usually provides modified hardware and software

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