

Draft NIST Special Publication 800-160, Volume 2

Revision 1

Developing Cyber-Resilient Systems:

A Systems Security Engineering Approach

RON ROSS
VICTORIA PILLITTERI
RICHARD GRAUBART
DEBORAH BODEAU
ROSALIE MCQUAID

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Developing Cyber-Resilient Systems:

A Systems Security Engineering Approach

RON ROSS

VICTORIA PILLITTERI

Computer Security Division

National Institute of Standards and Technology

RICHARD GRAUBART

DEBORAH BODEAU

ROSALIE MCQUAID

Cyber Resiliency and Innovative

Mission Engineering Department

The MITRE Corporation

McLean, VA

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1

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21

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22

National Institute of Standards and Technology
Attn: Computer Security Division, Information Technology Laboratory
100 Bureau Drive (Mail Stop 8930) Gaithersburg, MD 20899-8930
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23

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24

30

REPORTS ON COMPUTER SYSTEMS TECHNOLOGY

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32 (ITL) promotes the U.S. economy and public welfare by providing technical leadership for the
33 Nation's measurement and standards infrastructure. ITL develops tests, test methods, reference
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37 effective security of other than national security-related information in federal information
38 systems. The Special Publication 800-series reports on ITL's research, guidelines, and outreach
39 efforts in information systems security and privacy and its collaborative activities with industry,
40 government, and academic organizations.

41

ABSTRACT

42 This publication is used in conjunction with [ISO/IEC/IEEE 15288:2015, Systems and software](#)
43 [engineering—Systems life cycle processes](#), [NIST Special Publication \(SP\) 800-160, Volume 1,](#)
44 [Systems Security Engineering—Considerations for a Multidisciplinary Approach in the](#)
45 [Engineering of Trustworthy Secure Systems](#), and [NIST SP 800-37, Risk Management Framework](#)
46 [for Information Systems and Organizations—A System Life Cycle Approach for Security and](#)
47 [Privacy](#). It can be viewed as a handbook for achieving the identified cyber resiliency outcomes
48 based on a systems engineering perspective on system life cycle processes in conjunction with
49 risk management processes, allowing the experience and expertise of the organization to help
50 determine what is correct for its purpose. Organizations can select, adapt, and use some or all of
51 the cyber resiliency constructs (i.e., objectives, techniques, approaches, and design principles)
52 described in this publication and apply the constructs to the technical, operational, and threat
53 environments for which systems need to be engineered.

54

KEYWORDS

55 Advanced persistent threat; controls; cyber resiliency; cyber resiliency approaches; cyber
56 resiliency design principles; cyber resiliency engineering framework; cyber resiliency goals; cyber
57 resiliency objectives; cyber resiliency techniques; risk management strategy; system life cycle;
58 systems security engineering; trustworthiness.

59

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70

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76 gratefully acknowledge the significant contributions from individuals and organizations in the
77 public and private sectors, nationally and internationally, whose insightful, thoughtful, and
78 constructive comments improved the quality, thoroughness, and usefulness of this publication.

CYBER RESILIENCY IN THE SYSTEM LIFE CYCLE

NIST is working with the United States Air Force and the Air Force Research Laboratory (AFRL) to explore ways to incorporate the cyber resiliency constructs in this publication into the system development life cycle through the use of automated support tools. The use of such tools can help ensure that cyber resiliency requirements are clearly defined and can be more easily integrated into the system development life cycle. Automated tools can provide an efficient and effective vehicle for incorporating cyber resiliency capabilities into a variety of systems (e.g., weapons systems, space systems, command and control systems, industrial control systems, enterprise IT systems) using any established life cycle development process or approach (e.g., agile, waterfall, spiral, DevOps). Automation can also support the rapid testing and evaluation of cyber resiliency capabilities in critical systems to reduce the time to operational deployment.

79

80

NOTES TO REVIEWERS

81 This update constitutes the first revision to NIST Special Publication (SP) 800-160, Volume 2. In
82 addition to a general review and update of the entire publication, there are five significant
83 changes that either add new content or move current content to a new location. These include:

- 84 1. Updating the controls that support cyber resiliency to be consistent with NIST SP 800-
85 53, Revision 5 [[SP 800-53](#)]
- 86 2. Standardizing on a single threat taxonomy (i.e., Adversarial Tactics, Techniques, and
87 Common Knowledge [ATT&CK] framework) [[MITRE18](#)]
- 88 3. Providing a detailed mapping and analysis of the cyber resiliency implementation
89 approaches and supporting controls to the ATT&CK framework techniques, mitigations,
90 and candidate mitigations
- 91 4. Eliminating Appendix F on *Cyber Resiliency in the System Life Cycle* which will be
92 reflected in the update to NIST SP 800-160, Volume 1 [[SP 800-160 v1](#)]
- 93 5. Moving cyber resiliency use cases and examples in Appendices I and J to the NIST SP
94 800-160, Volume 2 website at <https://csrc.nist.gov/publications/detail/sp/800-160/vol-2/final> (available upon final publication)

96 Your feedback on this draft publication is important to us. We appreciate each contribution
97 from our reviewers. The very insightful comments from both the public and private sectors,
98 nationally and internationally, continue to help shape the final publication to ensure that it
99 meets the needs and expectations of our customers.

100

CALL FOR PATENT CLAIMS

101 This public review includes a call for information on essential patent claims (claims whose use
102 would be required for compliance with the guidance or requirements in this Information
103 Technology Laboratory (ITL) draft publication). Such guidance and/or requirements may be
104 directly stated in this ITL Publication or by reference to another publication. This call includes
105 disclosure, where known, of the existence of pending U.S. or foreign patent applications relating
106 to this ITL draft publication and of any relevant unexpired U.S. or foreign patents.

107 ITL may require from the patent holder, or a party authorized to make assurances on its behalf,
108 in written or electronic form, either:

- 109 a) assurance in the form of a general disclaimer to the effect that such party does not hold
110 and does not currently intend holding any essential patent claim(s); or
- 111 b) assurance that a license to such essential patent claim(s) will be made available to
112 applicants desiring to utilize the license for the purpose of complying with the guidance
113 or requirements in this ITL draft publication either:
 - 114 i) under reasonable terms and conditions that are demonstrably free of any unfair
115 discrimination; or
 - 116 ii) without compensation and under reasonable terms and conditions that are
117 demonstrably free of any unfair discrimination.

118 Such assurance shall indicate that the patent holder (or third party authorized to make
119 assurances on its behalf) will include in any documents transferring ownership of patents
120 subject to the assurance, provisions sufficient to ensure that the commitments in the assurance
121 are binding on the transferee, and that the transferee will similarly include appropriate
122 provisions in the event of future transfers with the goal of binding each successor-in-interest.
123

124 The assurance shall also indicate that it is intended to be binding on successors-in-interest
125 regardless of whether such provisions are included in the relevant transfer documents.

126 ***Such statements should be addressed to: security-engineering@nist.gov.***

127

EXECUTIVE SUMMARY

128 The goal of the NIST Systems Security Engineering initiative is to address security, safety, and
129 resiliency issues from the perspective of stakeholder requirements and protection needs using
130 established engineering processes to ensure that those requirements and needs are addressed
131 across the entire system life cycle to develop more trustworthy systems.¹ To that end, NIST
132 Special Publication (SP) 800-160, Volume 2, focuses on cyber resiliency engineering—an
133 emerging specialty systems engineering discipline applied in conjunction with resilience
134 engineering and systems security engineering to develop more survivable, trustworthy systems.
135 Cyber resiliency engineering intends to architect, design, develop, maintain, and sustain the
136 trustworthiness of systems with the capability to anticipate, withstand, recover from, and adapt
137 to adverse conditions, stresses, attacks, or compromises that use or are enabled by cyber
138 resources. From a risk management perspective, cyber resiliency is intended to reduce the
139 mission, business, organizational, or sector risk of depending on cyber resources.

140 This publication is intended to be used in conjunction with [ISO/IEC/IEEE 15288:2015, Systems](#)
141 *and software engineering—Systems life cycle processes*; [NIST SP 800-160, Volume 1, Systems](#)
142 *Security Engineering—Considerations for a Multidisciplinary Approach in the Engineering of*
143 *Trustworthy Secure Systems*; and [NIST SP 800-37, Risk Management Framework for Information](#)
144 *Systems and Organizations—A System Life Cycle Approach for Security and Privacy*. The
145 application of the principles in this publication—in combination with the system life cycle
146 processes in SP 800-160, Volume 1, and the risk management methodology in SP 800-37—can
147 be viewed as a handbook for achieving cyber resiliency outcomes. Guided and informed by
148 stakeholder protection needs, mission and business assurance needs, and stakeholder concerns
149 with cost, schedule, and performance, the cyber resiliency constructs, principles, and analysis
150 methods can be applied to critical systems to identify, prioritize, and implement solutions to
151 meet the unique cyber resiliency needs of organizations.

152

153 NIST SP 800-160, Volume 2, presents a cyber resiliency engineering framework to help aid in
154 understanding and applying cyber resiliency, a concept of use for the framework, and the
155 engineering considerations for implementing cyber resiliency in the system life cycle. The cyber
156 resiliency engineering framework constructs include goals, objectives, techniques, approaches,
157 and design principles. Organizations can select, adapt, and use some or all of the cyber resiliency
158 constructs in this publication and apply the constructs to the technical, operational, and threat
159 environments for which systems need to be engineered.

160 Building off of the cyber resiliency engineering framework, this publication also identifies
161 considerations for determining which cyber resiliency constructs are most relevant to a system-
162 of-interest and a tailorabile cyber resiliency analysis approach to apply the cyber resiliency
163 concepts, constructs, and practices to a system. The cyber resiliency analysis is intended to
164 determine whether the cyber resiliency properties and behaviors of a system-of-interest,

¹ In the context of systems engineering, trustworthiness means being trusted to fulfill whatever critical requirements may be needed for a particular component, subsystem, system, network, application, mission, enterprise, or other entity. Trustworthiness requirements can include attributes of safety, security, reliability, dependability, performance, resilience, and survivability under a wide range of potential adversity in the form of disruptions, hazards, and threats [[SP 800-160 v1](#)].

165 wherever it is in the life cycle, are sufficient for the organization using that system to meet its
166 mission assurance, business continuity, or other security requirements in a threat environment
167 that includes the advanced persistent threat (APT). A cyber resiliency analysis is performed with
168 the expectation that such analysis will support engineering and risk management decisions
169 about the system-of-interest.

170 The cyber resiliency engineering framework is supplemented by several technical appendices
171 that provide additional information to support its application, including:

- 172 • Background and contextual information on cyber resiliency
- 173 • Detailed descriptions of the individual cyber resiliency constructs (i.e., goals, objectives,
174 techniques, implementation approaches, design principles) that are part of the cyber
175 resiliency engineering framework
- 176 • Controls in [[SP 800-53](#)] which directly support cyber resiliency (including the questions used
177 to determine if controls support cyber resiliency, the relevant controls, and resiliency
178 techniques and approaches)
- 179 • An approach for adversary-oriented analysis of a system and applications of cyber resiliency,
180 a vocabulary to describe the current or potential effects of a set of mitigations, and a
181 representative analysis of how cyber resiliency approaches and controls could mitigate
182 adversary tactics, techniques, and procedures.

183

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DISCLAIMER

This publication is intended to be used in conjunction with and as a supplement to **International Standard ISO/IEC/IEEE 15288**, *Systems and software engineering — System life cycle processes*. It is strongly recommended that organizations using this publication obtain the standard in order to fully understand the context of the security-related activities and tasks in each of the system life cycle processes. Content from the international standard that is referenced in this publication is used with permission from the Institute of Electrical and Electronics Engineers and is noted as follows:

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RELATIONSHIP BETWEEN ISO 15288 AND OPERATIONAL RESILIENCE

Although the focus of [[ISO 15288](#)] is the systems and software engineering processes, operational resilience, which includes cyber resiliency for systems that include or depend on cyber resources, is addressed indirectly by requiring organization-wide commitment, resources, practices, and processes. The interacting elements in the definition of a *system* include layers of resilience in hardware, software, data, information, humans, processes, procedures, facilities, materials, and naturally occurring physical entities. This is important because if the organization's missions or business functions require sustainability during perturbations, disruptions, disturbances, or cyber attacks, then operational resilience practices and procedures must be applied to all of the system's assets. It would be of limited value to have resilience measures implemented in the software architecture if there is no redundancy and survivability in the hardware, if the communications networks are fragile, if critical personnel are not available (e.g., in a natural disaster or inclement weather) to operate and maintain the system, or if there are no facilities available for producing the organization's products and/or services.

242

243

SYSTEM RESILIENCE AND CYBER RESILIENCY

This publication focuses on cyber resiliency engineering as a specialty systems engineering discipline applied in conjunction with resilience engineering and systems security engineering. The relationship between these disciplines can be seen in the example of an automobile. An automobile contains many cyber resources including embedded control units for acceleration, braking, and engine control as well as entertainment and cellular communications systems. The automobile and its human operators can be viewed as a *system-of-interest* from the systems security engineering perspective as described in [[SP 800-160 v1](#)]. The system-of-interest has an assumed environment of operation (including the countries in which the vehicle is sold), which includes assumptions about the distribution of fuel or charging stations.

As a system element, the fuel or battery system includes cyber resources (e.g., to perform fuel consumption or battery use analysis and predict the remaining travel range). A *system resilience engineering analysis*—an analysis of the resilience of the system-of-interest to predictable, disruptive, or destructive events, due to accidents, structural failure, or human error—considers whether and how easily the operator could fail to notice a low-fuel or low-battery indicator. In addition, a system resilience (or system resiliency) engineering analysis considers whether the expected travel range of the vehicle is shorter than the expected maximum distance between fuel or charging stations in the intended operational environment.

A *cyber resiliency engineering analysis* of the fuel or battery system considers ways in which false information about the fuel level could be presented to the operator or to other system elements (e.g., an engine fail-safe which cuts off or deactivates if no fuel is being supplied) because of malware introduced into fuel consumption analysis. A cyber resiliency engineering analysis also considers ways in which other system elements could detect or compensate for the resulting misbehavior or prevent the malware from being introduced. While such an analysis could be made part of a general system resilience engineering analysis, it requires specialized expertise about how the APT can find and exploit vulnerabilities in the cyber resources, as well as about techniques that could be used to reduce the associated risks.

ADVERSARY PERSISTENCE AND LONG-TERM PRESENCE

Numerous reports of cyber incidents and cyber breaches indicate that extended periods of time transpired between the time an adversary initially established a presence in an organizational system by exploiting a vulnerability and when that presence was revealed or detected. In certain instances, the time periods before detection can be as long as months or years. In the worst case, the adversary's presence may never be detected.

The following examples illustrate the types of situations where an adversary can maintain a long-term presence or persistence in a system, even without attacking the system via cyberspace:

- Compromising the *pre-execution environment* of a system through a hardware or software implant (e.g., compromise of the firmware or microcode of a system element, such as a network switch or a router, that activates before initialization in the system's environment of operation). This is extremely difficult to detect and can result in compromise of the entire environment.
- Compromising the *software development tool-chain* (e.g., compilers, linkers, interpreters, continuous integration tools, code repositories). This allows malicious code to be inserted by the adversary without modifying the source code or without the knowledge of the software developers.
- Compromising a *semiconductor product or process* (e.g., malicious alteration to the hardware description language [HDL] of a microprocessor, a field-programmable gate array [FPGA], a digital signal processor [DSP], or an application-specific integrated circuit [ASIC]).

THREAT DETECTION AND CYBER RESILIENCY

Cyber resiliency is based on the recognition that adversaries can establish and maintain a covert presence in systems. Therefore, many of the cyber resiliency techniques and approaches are not predicated on the assumption of successfully detecting adversity including cyber attacks. These include the [Coordinated Protection](#), [Deception](#), [Diversity](#), [Non-Persistence](#), [Realignment](#), [Redundancy](#), [Substantiated Integrity](#), and [Unpredictability](#) techniques, and the [Fragmentation](#), [Distributed Functionality](#), [Predefined Segmentation](#), [Attribute-Based Usage Restriction](#), and [Trust-Based Privilege Management](#) approaches.

Other techniques and approaches can provide automatic response—or can support cyber defender responses—to detected indicators of possible or suspected adversity, or to warnings of potential forthcoming adverse conditions (including predictions of increased system load or announcements of planned outages of supporting services). These include the [Adaptive Response](#) technique and the [Functional Relocation of Sensors](#), [Functional Relocation of Cyber Resources](#), [Asset Mobility](#), [Dynamic Privileges](#), and [Dynamic Segmentation and Isolation](#) approaches.

Two cyber resiliency techniques directly involve the detection of adversity or its effects: These include [Analytic Monitoring](#) and [Contextual Awareness](#). The [Substantiated Integrity](#) technique and the [Consistency Analysis](#) approach support detection of some effects of adversity.

248

ERRATA

249 This table contains changes that have been incorporated into Special Publication 800-160, Volume
250 2, Revision 1. Errata updates can include corrections, clarifications, or other minor changes in the
251 publication that are either *editorial* or *substantive* in nature. Any potential updates for this
252 document that are not yet published in an errata update or revision—including additional issues
253 and potential corrections—will be posted as they are identified; see the SP 800-160 Volume 2,
254 Revision 1 publication details.

255

PROLOGUE

256 *"If a full on 'turn the lights off' cyber war were to happen today, we would lose. Think about that.*
257 *We would lose a cyber war. With a few clicks of the mouse, and in just a few seconds, hackers ...*
258 *could turn off our electricity, millions would lose heat, groceries would spoil, banking machines*
259 *would not work, and people could not get gasoline. It would be what we have seen down in Texas,*
260 *but on national scale and with no end in sight. That we have escaped a digital catastrophe thus far*
261 *is not due to skill. It is due to blind luck and restraint from our adversaries."*

262 **Mike Rogers, February 2021**
263 **Former Member of Congress, House Intelligence Committee**

264 *"Providing satisfactory security controls in a computer system is in itself a system design problem. A*
265 *combination of hardware, software, communications, physical, personnel and administrative-*
266 *procedural safeguards is required for comprehensive security. In particular, software safeguards*
267 *alone are not sufficient."*

268 **The Ware Report**
269 **Defense Science Board Task Force on Computer Security, 1970.**

270 *"This whole economic boom in cybersecurity seems largely to be a consequence of poor engineering."*
271 **Carl Landwehr**
272 **Communications of the ACM, February 2015**

273 *"Mission assurance requires systems that behave with predictability and proportionality."*
274 **General Michael Hayden**
275 **Former NSA and CIA Director, Syracuse University, October 2009**

276 *"In the past, it has been assumed that to show that a system is safe, it is sufficient to provide*
277 *assurance that the process for identifying the hazards has been as comprehensive as possible, and*
278 *that each identified hazard has one or more associated controls."*

279 *While historically this approach has been used reasonably effectively to ensure that known risks are*
280 *controlled, it has become increasingly apparent that evolution to a more holistic approach is*
281 *needed as systems become more complex and the cost of designing, building, and operating them*
282 *become more of an issue."*

283 **Preface, NASA Systems Safety Handbook, Volume 1**

284 CHAPTER ONE

285 INTRODUCTION

286 THE NEED FOR CYBER-RESILIENT SYSTEMS

287 The need for trustworthy secure systems² stems from a variety of *stakeholder* needs that
288 are driven by mission, business, and other objectives and concerns. The principles,
289 concepts, and practices for engineering trustworthy secure systems can be expressed in
290 various ways, depending on which aspect of trustworthiness is of concern to stakeholders. NIST
291 Special Publication (SP) 800-160, Volume 1 [[SP 800-160 v1](#)], provides guidance on systems
292 security engineering with an emphasis on protection against *asset loss*.³ In addition to security,
293 other aspects of trustworthiness include reliability, safety, and resilience. Specialty engineering
294 disciplines address different aspects of trustworthiness. While each discipline frames the
295 problem domain and the potential solution space for its aspect of trustworthiness somewhat
296 differently, [[SP 800-160 v1](#)] includes systems engineering processes to align the concepts,
297 frameworks, and analytic processes from multiple disciplines to make trade-offs within and
298 between the various aspects of trustworthiness applicable to a *system-of-interest*.⁴

299 NIST SP 800-160, Volume 2, focuses on the property of *cyber resiliency*, which has a strong
300 relationship to security and resilience but which provides a distinctive framework for its
301 identified problem domain and solution space. Cyber resiliency is the ability to anticipate,
302 withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on
303 systems that use or are enabled by cyber resources.⁵

304 Cyber resiliency can be sought at multiple levels, including for system elements, systems,
305 missions or business functions and the system-of-systems which support those functions,
306 organizations, sectors, regions, the Nation, or transnational missions/business functions. From
307 an engineering perspective, cyber resiliency is an emergent quality property of an engineered
308 system, where an “engineered system” can be a system element made up of constituent
309 components, a system, or a system-of-systems. Cyber-resilient systems are those systems that
310 have security measures or safeguards “built in” as a foundational part of the architecture and
311 design and that display a high level of resiliency. Thus, cyber-resilient systems can withstand
312 cyber attacks, faults, and failures and continue to operate in a degraded or debilitated state to

² A *system* is a combination of interacting elements organized to achieve one or more stated purpose. The interacting system elements that compose a system include hardware, software, data, humans, processes, procedures, facilities, materials, and naturally occurring entities [[ISO 15288](#)].

³ An *asset* refers to an item of value to stakeholders. Assets may be tangible (e.g., a physical item, such as hardware, firmware, computing platform, network device, or other technology component, or individuals in key or defined roles in organizations) or intangible (e.g., data, information, software, trademark, copyright, patent, intellectual property, image, or reputation). Refer to [[SP 800-160 v1](#)] for the systems security engineering perspective on assets.

⁴ A *system-of-interest* is a system whose life cycle is under consideration in the context of [[ISO 15288](#)]. A system-of-interest can also be viewed as the system that is the focus of the systems engineering effort. The system-of-interest contains system elements, system element interconnections, and the environment in which they are placed.

⁵ The term *adversity* is used in this publication to mean adverse conditions, stresses, attacks, or compromises and is consistent with the use of the term in [[SP 800-160 v1](#)] as disruptions, hazards, and threats. Adversity in the context of the definition of cyber resiliency specifically includes but is not limited to cyber attacks. For example, cyber resiliency engineering analysis considers the potential consequences of physical destruction of a cyber resource to the system-of-interest of which that resource is a system element.

313 carry out the mission-essential functions of the organization. From an enterprise risk
314 management perspective, cyber resiliency is intended to reduce the mission, business,
315 organizational, or sector risk of depending on cyber resources.

316 Cyber resiliency supports mission assurance in a contested environment for missions that
317 depend on systems which include cyber resources. A *cyber resource* is an information resource
318 which creates, stores, processes, manages, transmits, or disposes of information in electronic
319 form and which can be accessed via a network or using networking methods. However, some
320 information resources are specifically designed to be accessed using a networking method only
321 intermittently (e.g., via a low-power connection to check the status of an insulin pump, via a
322 wired connection to upgrade software in an embedded avionic device). These cyber resources
323 are characterized as operating primarily in a disconnected or non-networked mode.⁶

CYBER-RESILIENT SYSTEMS

Cyber-resilient systems operate somewhat like the human body. The human body has a powerful immune system that absorbs a constant barrage of environmental hazards and provides the necessary defense mechanisms to maintain a healthy state. The human body also has self-repair systems to recover from illnesses and injuries when defenses are breached. But cyber-resilient systems, like the human body, cannot defend against all hazards at all times. While the body cannot always recover to the same state of health as before an injury or illness, it can adapt. Similarly, cyber-resilient systems can recover minimal essential functionality. Understanding the limitations of individuals, organizations, and engineered systems is fundamental to managing risk.

324
325
326 Systems increasingly incorporate cyber resources as *system elements*. As a result, systems are
327 susceptible to harms resulting from the effects of adversity on cyber resources and particularly
328 to harms resulting from cyber attacks. The cyber resiliency problem is defined as how to achieve
329 adequate mission resilience by providing (1) adequate *system resilience*⁷ and (2) adequate
330 mission/business function and operational/organizational resilience in the presence of possible
331 adversities that affect cyber resources. The cyber resiliency problem domain overlaps with the
332 security problem domain since a system should be *securely resilient*.⁸ The cyber resiliency
333 problem domain is guided and informed by an understanding of the threat landscape and, in
334 particular, the *advanced persistent threat* (APT). The APT is an adversary that possesses
335 significant levels of expertise and resources which allow it to create opportunities to achieve its
336 objectives by using multiple attack vectors, including cyber, physical, and deception. These
337 objectives typically include establishing and extending footholds within the systems of the

⁶ Some information resources, which include computing hardware, software, and stored information, are designed to be inaccessible via networking methods but can be manipulated physically or electronically to yield information or to change behavior (e.g., side-channel attacks on embedded cryptographic hardware). Such system elements may also be considered cyber resources for the purposes of cyber resiliency engineering analysis.

⁷ *System resilience* is defined by the INCOSE Resilient Systems Working Group (RSWG) as “the capability of a system with specific characteristics before, during, and after a disruption to absorb the disruption, recover to an acceptable level of performance, and sustain that level for an acceptable period of time [INCOSE11].”

⁸ The term *securely resilient* refers to the system’s ability to preserve a secure state despite disruption, including the system transitions between normal and degraded modes. A primary objective of systems security engineering [SP 800-160 v1] is ensuring that the system is securely resilient.

338 targeted organizations for the express purposes of exfiltrating information; undermining or
339 impeding critical aspects of a mission, program, or organization; or positioning itself to carry out
340 these objectives in the future. The APT pursues its objectives repeatedly over an extended
341 period, adapts to defenders' efforts to resist it, and is determined to maintain the level of
342 interaction needed to execute its objectives [[SP 800-39](#)] [[CNSSI 4009](#)].⁹

343 All discussions of cyber resiliency focus on assuring mission or business functions and are
344 predicated on the assumption that the adversary will breach defenses and establish a long-term
345 presence in organizational systems. A *cyber-resilient system* is a system that provides a degree
346 of cyber resiliency commensurate with the system's criticality. It treats cyber resiliency as one
347 aspect of trustworthiness that requires assurance in conjunction with other aspects, such as
348 security, reliability, and safety.

349 1.1 PURPOSE AND APPLICABILITY

350 The purpose of this document is to supplement [[SP 800-160 v1](#)] and [[SP 800-37](#)] (or other risk
351 management processes or methodologies) with guidance on how to apply cyber resiliency
352 concepts, constructs, and engineering practices as part of systems security engineering and risk
353 management for systems and organizations. This document identifies considerations of the
354 engineering of systems that include the following circumstances or systems that depend on
355 cyber resources. Circumstances or types of systems to which this document applies include:¹⁰

- 356 • **Circumstances:** New systems, reactive modifications to fielded systems, planned upgrades
357 to fielded systems while continuing to sustain day-to-day operations, evolution of systems,
358 and retirement of systems
- 359 • **Types of systems:**
 - 360 - General-purpose or multi-use systems (e.g., enterprise information technology [EIT]),
361 shared services, or common infrastructures
 - 362 - Dedicated or special-purpose systems (e.g., security-dedicated or security-purposed
363 systems, cyber-physical systems [CPS],¹¹ Internet of Things [IoT], or Network of Things
364 [NoT]¹²)
 - 365 - Large-scale processing environments
 - 366 - Systems-of-systems (e.g., critical infrastructure systems [CIS])

⁹ While some sources define the APT to be an adversary at Tier V or Tier VI in the threat model in [[DSB13](#)], in particular, to be a state actor, the definition used in this publication includes any actors with the characteristics described above. The above definition also includes adversaries that subvert the supply chain to compromise cyber resources, which are subsequently made part of the system-of-interest. As discussed in [Chapter Two](#) and [Section D.2](#), the APT is a crucial aspect of the threat landscape for cyber resiliency engineering.

¹⁰ This list is not intended to be exhaustive or mutually exclusive. Circumstances and types of systems are discussed in more detail in [Section 2.2](#) and [Section 3.1.3](#).

¹¹ A cyber-physical system (CPS) is a system that includes engineered interacting networks of computational and physical components. CPSs range from simple devices to complex systems-of-systems. A CPS device is a device that has an element of computation and interacts with the physical world through sensing and actuation [[SP 1500-201](#)].

¹² A Network of Things (NoT) is a system consisting of devices that include a sensor and a communications capability, a network, software that aggregates sensor data, and an external utility (i.e., a software or hardware product or service that executes processes or feeds data into the system) [[SP 800-183](#)].

367 1.2 TARGET AUDIENCE

368 This publication is intended for systems security engineering and other professionals who are
369 responsible for the activities and tasks related to the system life cycle processes in [[SP 800-160](#)
370 [v1](#)], the risk management processes in [[SP 800-39](#)], or the Risk Management Framework (RMF)
371 in [[SP 800-37](#)].¹³ The term *systems security engineer* is used in this publication to include those
372 security professionals who perform any of the activities and tasks in [[SP 800-160 v1](#)]. This
373 publication can also be used by professionals who perform other system life cycle activities that
374 impact trustworthiness or who perform activities related to the education or training of systems
375 engineers and systems security engineers. These include but are not limited to:

- 376 • Individuals with systems engineering, architecture, design, development, and integration
377 responsibilities
- 378 • Individuals with software engineering, architecture, design, development, integration, and
379 software maintenance responsibilities
- 380 • Individuals with security governance, risk management, and oversight responsibilities,
381 particularly those defined in [[SP 800-37](#)]
- 382 • Individuals with independent security verification, validation, testing, evaluation, auditing,
383 assessment, inspection, and monitoring responsibilities
- 384 • Individuals with system security administration, operations, maintenance, sustainment,
385 logistics, and support responsibilities
- 386 • Individuals with acquisition, budgeting, and project management responsibilities;
- 387 • Providers of technology products, systems, or services
- 388 • Academic institutions offering systems security engineering and related programs

389 This publication assumes that the systems security engineering activities in [[SP 800-160 v1](#)] and
390 risk management processes in [[SP 800-37](#)] are performed under the auspices of or within an
391 organization (referred to as “the organization” in this document).¹⁴ The activities and processes
392 take into consideration the concerns of a variety of stakeholders, within and external to the
393 organization. The organization—through systems security engineering and risk management
394 activities—identifies stakeholders, elicits their concerns, and represents those concerns in the
395 systems security engineering and risk management activities.

396 1.3 HOW TO USE THIS PUBLICATION

397 This publication is intended to be used in conjunction with [[SP 800-160 v1](#)] and is designed to be
398 flexible in its application to meet the diverse and changing needs of organizations. It is not
399 intended to provide a specific recipe for execution. Rather, the publication can be viewed as a
400 catalog or handbook for achieving the identified cyber resiliency outcomes from a systems

¹³ This includes security and risk management practitioners with significant responsibilities for the protection of existing systems, information, and the information technology infrastructure within enterprises (i.e., the installed base). Such practitioners may use the cyber resiliency content in this publication in other than engineering-based system life cycle processes. These application areas may include use of the *Risk Management Framework* [[SP 800-37](#)], the controls in [[SP 800-53](#)], or the *Framework for Improving Critical Infrastructure Cybersecurity* [[NIST CSF](#)] where such applications have cyber resiliency-related concerns.

¹⁴ Systems security engineering and risk management apply to systems-of-systems in which multiple organizations are responsible for constituent systems. In such situations, systems security engineering and risk management activities are performed within individual organizations (each an instance of “the organization”) and supported by cooperation or coordination across those organizations.

401 engineering perspective on system life cycle processes, leveraging the experience and expertise
402 of the engineering organization to determine what is correct for its purpose. Stakeholders
403 choosing to use this guidance can employ some or all of the cyber resiliency constructs (i.e.,
404 goals, objectives, techniques, approaches, and design principles) as well as the analytic and life
405 cycle processes, tailoring them to the technical, operational, and threat environments for which
406 systems need to be engineered. In addition, organizations choosing to use this guidance for their
407 systems security engineering efforts can select and employ some or all of the thirty processes in
408 [ISO 15288] and some or all of the security-related activities and tasks defined for each process.
409 Note that there are process dependencies in [ISO 15288]. The successful completion of some
410 activities and tasks invokes other processes or leverages the results of other processes.

411 The system life cycle processes can be used for new systems, system upgrades, or systems that
412 are being repurposed. The processes can be employed at any stage of the system life cycle and
413 can take advantage of any system or software development methodology, including waterfall,
414 spiral, or agile. The life cycle processes can also be applied recursively, iteratively, concurrently,
415 sequentially, or in parallel and to any system regardless of its size, complexity, purpose, scope,
416 environment of operation, or special nature.

417 The full extent of the application of the content in this publication is informed by stakeholder
418 needs, organizational capability, and cyber resiliency goals and objectives, as well as concerns
419 for cost, schedule, and performance. The tailorable nature of the engineering activities and tasks
420 and the system life cycle processes help to ensure that the specific systems resulting from the
421 application of the security design principles and concepts have a level of trustworthiness
422 deemed sufficient to protect stakeholders from suffering unacceptable losses of assets and the
423 associated consequences. Such trustworthiness is made possible by the rigorous application of
424 those cyber resiliency design principles, constructs, and concepts within a structured set of
425 processes that provides the necessary evidence and transparency to support risk-informed
426 decision making and trades.

427 **1.4 PUBLICATION ORGANIZATION**

428 The remainder of this special publication is organized as follows:

- 429 • [**Chapter Two**](#) describes the framework for cyber resiliency engineering.
- 430 • [**Chapter Three**](#) describes considerations for selecting and prioritizing cyber resiliency
431 techniques and implementation approaches and presents a tailorble process for applying
432 cyber resiliency concepts, constructs, and practices to a system.

433 The following sections provide additional cyber resiliency-related information, including:

- 434 • [**References**](#)¹⁵
- 435 • [**Appendix A**](#): Glossary
- 436 • [**Appendix B**](#): Acronyms
- 437 • [**Appendix C**](#): Background
- 438 • [**Appendix D**](#): Cyber Resiliency Constructs

¹⁵ Unless otherwise stated, all references to NIST publications refer to the most recent version of those publications.

- 439 • [**Appendix E**](#): Controls Supporting Cyber Resiliency

- 440 • [**Appendix F**](#): Adversary-Oriented Analysis

441

442

CYBER RESILIENCY—A NECESSARY SYSTEM PROPERTY

Most engineered systems incorporate or depend on cyber resources and are therefore, highly susceptible to adversity that affects such resources and particularly to cyber attacks. Harms resulting from cyber attacks and the effects of faults, failures, and human errors—which adversaries can leverage and emulate—are experienced at the organizational level, mission or business process level, and the system level [SP 800-39]. The management of cyber risks is thus an increasingly crucial aspect of any risk management program.

Cyber resiliency is defined as “the ability to anticipate, withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on systems that use or are enabled by cyber resources.” (See [Section C.1](#) for additional information on how this definition relates to other resilience-related definitions.) Systems with this property are characterized by security measures that are “built in” as a foundational part of the architecture and design. Moreover, these systems can withstand cyber attacks, faults, and failures and can continue to operate even in a degraded or debilitated state, carrying out mission-essential functions, and ensuring that the other aspects of trustworthiness (i.e., safety and information security) are preserved.

Cyber resiliency must be provided in a cyber-contested environment that includes the Advanced Persistent Threat (APT). Therefore, any discussion of cyber resiliency is predicated on the assumption that adversaries will breach defenses and that, whether via breaches or via supply chain attacks, adversaries will establish a long-term presence in organizational systems. (See [Section C.2](#) for more information on the characteristics of cyber resiliency.) The assumption of a sophisticated, well-resourced, and persistent adversary whose presence in systems can go undetected for extended periods is a key differentiator between cyber resiliency and other aspects of trustworthiness.

443

444 CHAPTER TWO

445 THE FUNDAMENTALS

446 UNDERSTANDING THE CONCEPTS ASSOCIATED WITH CYBER RESILIENCY

447 This section presents an engineering framework for understanding and applying cyber
448 resiliency, the cyber resiliency constructs that are part of the framework, a concept of use
449 for the framework, and engineering considerations for implementing cyber resiliency in
450 the system life cycle. The discussion relies on several terms including cyber resiliency concepts,
451 constructs, engineering practices, and solutions.

452 Cyber resiliency *concepts* are related to the problem domain and the solution set for cyber
453 resiliency. The concepts are represented in cyber resiliency risk models and by cyber resiliency
454 constructs.¹⁶ The *constructs* are the basic elements (i.e., building blocks) of the cyber resiliency
455 engineering framework and include goals, objectives, techniques, implementation approaches,
456 and design principles.¹⁷ The framework provides a way to understand the cyber resiliency
457 problem and solution domain. Cyber resiliency goals and objectives identify the “what” of cyber
458 resiliency—that is, what properties and behaviors are integral to cyber-resilient systems. Cyber
459 resiliency techniques, implementation approaches, and design principles characterize the ways
460 of achieving or improving resilience in the face of threats to systems and system components
461 (i.e., the “how” of cyber resiliency). Cyber resiliency constructs address both adversarial and
462 non-adversarial threats from cyber and non-cyber sources. The concern for cyber resiliency
463 focuses on aspects of trustworthiness—in particular, security and resilience—and risk from the
464 perspective of mission assurance against determined adversaries (e.g., the APT).

465 Cyber resiliency *engineering practices* are the methods, processes, modeling, and analytical
466 techniques used to identify and analyze proposed cyber resiliency solutions. The application of
467 cyber resiliency engineering practices in system life cycle processes ensures that cyber resiliency
468 *solutions* are driven by stakeholder requirements and protection needs, which, in turn, guide
469 and inform the development of system requirements for the system-of-interest [[ISO 15288, SP](#)
470 [800-160 v1](#)]. Such solutions consist of combinations of technologies, architectural decisions,
471 systems engineering processes, and operational policies, processes, procedures, or practices
472 that solve problems in the cyber resiliency domain. That is, they provide a sufficient level of
473 cyber resiliency to meet stakeholder needs and reduce risks to organizational mission or
474 business capabilities in the presence of a variety of threat sources, including the APT.

475 Cyber resiliency *solutions* use cyber resiliency techniques and approaches to implementing
476 those techniques, as described in [Section 2.1.3](#). Cyber resiliency solutions apply the design
477 principles described in [Section 2.1.4](#). Cyber resiliency solutions typically implement mechanisms
478 (e.g., controls and control enhancements defined in [[SP 800-53](#)]) that apply one or more cyber
479 resiliency techniques or implementation approaches or that are intended to achieve one or
480 more cyber resiliency objectives. These mechanisms are selected in response to the security and
481 cyber resiliency requirements defined as part of the system life cycle requirements engineering

¹⁶ As discussed in [Section D.1](#), cyber resiliency concepts and constructs are informed by definitions and frameworks related to other forms of resilience as well as system survivability. A reader unfamiliar with the concept of resilience may benefit from reading that appendix before this section.

¹⁷ Additional constructs (e.g., sub-objectives, capabilities) may be used in some modeling and analytic practices.

482 process described in [SP 800-160 v1] or to mitigate security and cyber resiliency risks that arise
 483 from architectural or design decisions.

484 2.1 CYBER RESILIENCY ENGINEERING FRAMEWORK

485 The following sections provide a description of the framework for cyber resiliency engineering.¹⁸
 486 The framework constructs include cyber resiliency goals, objectives, techniques, approaches,
 487 and design principles. The relationship among constructs is also described. These constructs, like
 488 cyber resiliency, can be applied at levels beyond the system (e.g., mission or business function
 489 level, organizational level, or sector level). [Table 1](#) summarizes the definition and purpose of
 490 each construct and how each construct is applied at the system level.

491 **TABLE 1: CYBER RESILIENCY CONSTRUCTS**

| CONSTRUCT | DEFINITION, PURPOSE, AND APPLICATION AT THE SYSTEM LEVEL |
|-----------------------------------|--|
| GOAL | A high-level statement supporting (or focusing on) one aspect (i.e., anticipate, withstand, recover, adapt) in the definition of cyber resiliency. Purpose: Align the definition of cyber resiliency with definitions of other types of resilience. Application: Can be used to express high-level stakeholder concerns, goals, or priorities. |
| OBJECTIVE | A high-level statement (designed to be restated in system-specific and stakeholder-specific terms) of what a system must achieve in its operational environment and throughout its life cycle to meet stakeholder needs for mission assurance and resilient security; the objectives are more specific than goals and more relatable to threats. Purpose: Enable stakeholders and systems engineers to reach a common understanding of cyber resiliency concerns and priorities; facilitate the definition of metrics or measures of effectiveness (MOEs). Application: Used in scoring methods or summaries of analyses (e.g., cyber resiliency posture assessments). |
| Sub-Objective | A statement, subsidiary to a cyber resiliency objective, which emphasizes different aspects of that objective or identifies methods to achieve that objective. Purpose: Serve as a step in the hierarchical refinement of an objective into activities or capabilities for which performance measures can be defined. Application: Used in scoring methods or analyses; may be reflected in system functional requirements. |
| Activity or Capability | A statement of a capability or action which supports the achievement of a sub-objective and, hence, an objective. Purpose: Facilitate the definition of metrics or MOEs. While a representative set of activities or capabilities have been identified in [Bodeau18b] , these are intended solely as a starting point for selection, tailoring, and prioritization. Application: Used in scoring methods or analyses; reflected in system functional requirements. |
| STRATEGIC DESIGN PRINCIPLE | A high-level statement which reflects an aspect of the risk management strategy that informs systems security engineering practices for an organization, mission, or system. |

¹⁸ The cyber resiliency engineering framework described in this publication is based on and consistent with the *Cyber Resiliency Engineering Framework* developed by The MITRE Corporation [\[Bodeau11\]](#).

| CONSTRUCT | DEFINITION, PURPOSE, AND APPLICATION AT THE SYSTEM LEVEL |
|-----------------------------|---|
| | <p>Purpose: Guide and inform engineering analyses and risk analyses throughout the system life cycle. Highlight different structural design principles, cyber resiliency techniques, and implementation approaches.</p> <p>Application: Included, cited, or restated in system non-functional requirements (e.g., requirements in a Statement of Work [SOW] for analyses or documentation).</p> |
| STRUCTURAL DESIGN PRINCIPLE | <p>A statement which captures experience in defining system architectures and designs.</p> <p>Purpose: Guide and inform design and implementation decisions throughout the system life cycle. Highlight different cyber resiliency techniques and implementation approaches.</p> <p>Application: Included, cited, or restated in system non-functional requirements (e.g., Statement of Work [SOW] requirements for analyses or documentation); used in systems engineering to guide the use of techniques, implementation approaches, technologies, and practices.</p> |
| TECHNIQUE | <p>A set or class of technologies, processes, or practices providing capabilities to achieve one or more cyber resiliency objectives.</p> <p>Purpose: Characterize technologies, practices, products, controls, or requirements so that their contribution to cyber resiliency can be understood.</p> <p>Application: Used in engineering analysis to screen technologies, practices, products, controls, solutions, or requirements; used in the system by implementing or integrating technologies, practices, products, or solutions.</p> |
| IMPLEMENTATION APPROACH | <p>A subset of the technologies and processes of a cyber resiliency technique, defined by how the capabilities are implemented.</p> <p>Purpose: Characterize technologies, practices, products, controls, or requirements so that their contribution to cyber resiliency and their potential effects on threat events can be understood.</p> <p>Application: Used in engineering analysis to screen technologies, practices, products, controls, solutions, or requirements; used in the system by implementing or integrating technologies, practices, products, or solutions.</p> |
| SOLUTION | <p>A combination of technologies, architectural decisions, systems engineering processes, and operational processes, procedures, or practices that solves a problem in the cyber resiliency domain.</p> <p>Purpose: Provide a sufficient level of cyber resiliency to meet stakeholder needs and reduce risks to mission or business capabilities in the presence of advanced persistent threats.</p> <p>Application: Integrated into the system or its operational environment.</p> |
| MITIGATION | <p>An action or practice, using a technology, control, solution, or a set of these, that reduces the level of risk associated with a threat event or threat scenario.</p> <p>Purpose: Characterize actions, practices, approaches, controls, solutions, or combinations of these in terms of their potential effects on threat events, threat scenarios, or risks.</p> <p>Application: Integrated into the system as it is used.</p> |

492

493 **2.1.1 Cyber Resiliency Goals**

494 Cyber resiliency, like security, is a concern at multiple levels in an organization. The four cyber
 495 resiliency goals, which are common to many resilience definitions, are included in the definition
 496 and the cyber resiliency engineering framework to provide linkage between risk management
 497 decisions at the mission and business process level and at the system level with those at the

498 organizational level. Organizational risk management strategies can use the cyber resiliency
 499 goals and associated strategies to incorporate cyber resiliency.¹⁹

500 For cyber resiliency engineering analysis, cyber resiliency objectives²⁰ rather than goals are the
 501 starting point. The term *adversity*, as used in the cyber resiliency goals in [Table 2](#), includes
 502 stealthy, persistent, sophisticated, and well-resourced adversaries (i.e., the APT) who may have
 503 compromised system components and established a foothold within an organization's systems.

504

TABLE 2: CYBER RESILIENCY GOALS

| GOAL | DESCRIPTION |
|-------------------|--|
| ANTICIPATE | Maintain a state of informed preparedness for adversity. Discussion: Adversity refers to adverse conditions, stresses, attacks, or compromises on cyber resources. Adverse conditions can include natural disasters and structural failures (e.g., power failures). Stresses can include unexpectedly high-performance loads. Adversity can be caused or taken advantage of by an APT actor. Informed preparedness involves contingency planning, including plans for mitigating attacks as well as for responding to discoveries of vulnerabilities or supply chain compromises. Cyber threat intelligence (CTI) provides vital information for informed preparedness. |
| WITHSTAND | Continue essential mission or business functions despite adversity. Discussion: Detection is not required for this goal to be meaningful and achievable. An APT actor's activities may be undetected, or they may be detected but incorrectly attributed to user error or other stresses. Identification of essential organizational missions or business functions is necessary to achieve this goal. In addition, supporting processes, systems, services, networks, and infrastructures must also be identified. The criticality of resources and capabilities of essential functions can vary over time. |
| RECOVER | Restore mission or business functions during and after adversity. Discussion: The restoration of functions (including data) can be incremental. A key challenge is to determine how much trust can be placed in restored functions and data as restoration progresses. Other threat events or conditions in the operational or technical environment can interfere with recovery, and an APT actor may seek to take advantage of confusion about recovery processes to establish a new foothold in the organization's systems. |
| ADAPT | Modify mission or business functions and/or supporting capabilities in response to predicted changes in the technical, operational, or threat environments. Discussion: Change can occur at different scales and over different time frames, so tactical and strategic adaption may be needed. Modification can be applied to processes and procedures as well as technology. Changes in the technical environment can include emerging technologies (e.g., artificial intelligence, 5G, Internet of Things) as well as the retirement of obsolete products. Changes in the operational environment of the organization can result from regulatory or policy changes, as well as the introduction of new business processes or workflows. Analyses of such changes and of interactions between changes, can reveal how these could modify the attack surface or introduce fragility. |

505

¹⁹ See [Appendix C](#).²⁰ See [Section 2.1.2](#).

506 **2.1.2 Cyber Resiliency Objectives**

507 Cyber resiliency objectives are more specific statements of what a system must achieve in its
 508 operational environment and throughout its life cycle to meet stakeholder needs for mission
 509 assurance and resilient security. Cyber resiliency objectives,²¹ as described in [Table 3](#), support
 510 interpretation, facilitate prioritization and assessment, and enable the development of
 511 questions such as:

- 512 • What does each cyber resiliency objective mean in the context of the organization and the
 513 mission or business process that the system is intended to support?
- 514 • Which cyber resiliency objectives are most important to a given stakeholder?
- 515 • To what degree can each cyber resiliency objective be achieved?
- 516 • How quickly and cost-effectively can each cyber resiliency objective be achieved?
- 517 • With what degree of confidence or trust can each cyber resiliency objective be achieved?

518 **TABLE 3: CYBER RESILIENCY OBJECTIVES²²**

| OBJECTIVE | DESCRIPTION |
|------------------|---|
| PREVENT OR AVOID | <p>Preclude the successful execution of an attack or the realization of adverse conditions.</p> <p>Discussion: This objective relates to an organization's preferences for different risk response approaches. Risk avoidance or threat avoidance is one possible risk response approach and is feasible under restricted circumstances. Preventing a threat event from occurring is another possible risk response, similarly feasible under restricted circumstances.</p> |
| PREPARE | <p>Maintain a set of realistic courses of action that address predicted or anticipated adversity.</p> <p>Discussion: This objective is driven by the recognition that adversity will occur. It specifically relates to an organization's contingency planning, continuity of operations plan (COOP), training, exercises, and incident response and recovery plans for critical systems and infrastructures.</p> |
| CONTINUE | <p>Maximize the duration and viability of essential mission or business functions during adversity.</p> <p>Discussion: This objective specifically relates to essential functions. Its assessment is aligned with the definition of performance parameters, analysis of functional dependencies, and identification of critical assets. Note that shared services and common infrastructures, while not identified as essential <i>per se</i>, may be necessary to essential functions and thus related to this objective.</p> |
| CONSTRAIN | <p>Limit damage²³ from adversity.</p> |

²¹ The term *objective* is defined and used in multiple ways. In this document, uses are qualified (e.g., cyber resiliency objectives, security objectives [[FIPS 199](#)], adversary objectives [[MITRE18](#)], engineering objectives or purposes [[ISO 24765](#)]) for clarity. Cyber resiliency goals and objectives can be viewed as two levels of fundamental objectives, as used in Decision Theory [[Clemen13](#)]. Alternately, cyber resiliency goals can be viewed as fundamental objectives and cyber resiliency objectives as enabling objectives [[Brtis16](#)]. By contrast, cyber resiliency techniques can be viewed as means objectives [[Clemen13](#)].

²² See [Appendix D](#) for specific relationships between objectives and goals.

²³ From the perspective of cyber resiliency, *damage* can be to the organization (e.g., loss of reputation, increased existential risk), missions or business functions (e.g., decrease in the ability to complete the current mission and to accomplish future missions), security (e.g., decrease in the ability to achieve the security objectives of integrity, availability, and confidentiality or decrease in the ability to prevent, detect, and respond to cyber incidents), the system (e.g., decrease in the ability to meet system requirements or unauthorized use of system resources), or specific system elements (e.g., physical destruction; corruption, modification, or fabrication of information).

| OBJECTIVE | DESCRIPTION |
|--------------|---|
| | Discussion: This objective specifically applies to critical or high-value assets—those cyber assets which contain or process sensitive information, are mission-essential, or provide infrastructure services to mission-essential capabilities. |
| RECONSTITUTE | <p>Restore as much mission or business functionality as possible after adversity.</p> <p>Discussion: This objective relates to essential functions, critical assets, and the services and infrastructures on which they depend. A key aspect of achieving this objective is ensuring that recovery, restoration, or reconstitution efforts result in trustworthy resources. This objective is not predicated on analysis of the source of adversity (e.g., attribution) and can be achieved even without detection of adversity via ongoing efforts to ensure the timely and correct availability of resources.</p> |
| UNDERSTAND | <p>Maintain useful representations of mission and business dependencies and the status of resources with respect to possible adversity.</p> <p>Discussion: This objective supports the achievement of all other objectives, most notably Prepare, Reconstitute, Transform, and Re-Architect. An organization’s plans for continuous diagnostics and mitigation (CDM), infrastructure services, and other services support this objective. The detection of anomalies, particularly suspicious or unexpected events or conditions, also supports achieving this objective. However, this objective includes understanding resource dependencies and status independent of detection. This objective also relates to an organization’s use of forensics and cyber threat intelligence information sharing.</p> |
| TRANSFORM | <p>Modify mission or business functions and supporting processes to handle adversity and address environmental changes more effectively.</p> <p>Discussion: This objective specifically applies to workflows for essential functions, supporting processes, and incident response and recovery plans for critical assets and essential functions. Tactical modifications are usually procedural or configuration-related; longer-term modifications can involve restructuring operational processes or governance responsibilities while leaving the underlying technical architecture unchanged.</p> |
| RE-ARCHITECT | <p>Modify architectures to handle adversity and address environmental changes more effectively.</p> <p>Discussion: This objective specifically applies to system architectures and mission architectures, which include the technical architecture of the system-of-systems supporting a mission or business function. In addition, this objective applies to architectures for critical infrastructures and services, which frequently support multiple essential functions.</p> |

519

520 Because stakeholders may find the cyber resiliency objectives difficult to relate to their specific
 521 concerns, the objectives can be tailored to reflect the organization’s missions and business
 522 functions or operational concept for the system-of-interest. Tailoring the cyber resiliency
 523 objectives can also help stakeholders determine which objectives apply and the priority to
 524 assign to each objective. Cyber resiliency objectives can be hierarchically refined to emphasize
 525 the different aspects of an objective or the methods to achieve an objective, thus creating sub-
 526 objectives.²⁴ Cyber resiliency objectives (and, as needed to help stakeholders interpret the
 527 objectives for their concerns, sub-objectives) enable stakeholders to assert their different
 528 resiliency priorities based on organizational missions or business functions.

²⁴ Table D-1 in Appendix D provides representative examples of sub-objectives.

529 2.1.3 Cyber Resiliency Techniques and Approaches

530 Cyber resiliency goals and objectives provide a vocabulary for describing what properties and
531 capabilities are needed. Cyber resiliency techniques, approaches, and design principles
532 (discussed in [Section 2.1.4](#)) provide a vocabulary for discussing how a system can achieve its
533 cyber resiliency goals and objectives. A cyber resiliency technique is a set or class of practices
534 and technologies intended to achieve one or more goals or objectives by providing capabilities.
535 The following 14 techniques are part of the cyber resiliency engineering framework:

- 536 1. **[Adaptive Response](#)**: Implement agile courses of action to manage risks.
- 537 2. **[Analytic Monitoring](#)**: Monitor and analyze a wide range of properties and behaviors on
538 an ongoing basis and in a coordinated way.
- 539 3. **[Contextual Awareness](#)**: Construct and maintain current representations of the posture
540 of missions or business functions considering threat events and courses of action.
- 541 4. **[Coordinated Protection](#)**: Ensure that protection mechanisms operate in a coordinated
542 and effective manner.
- 543 5. **[Deception](#)**: Mislead, confuse, hide critical assets from, or expose covertly tainted assets
544 to the adversary.
- 545 6. **[Diversity](#)**: Use heterogeneity to minimize common mode failures, particularly threat
546 events exploiting common vulnerabilities.
- 547 7. **[Dynamic Positioning](#)**: Distribute and dynamically relocate functionality or system
548 resources.
- 549 8. **[Non-Persistence](#)**: Generate and retain resources as needed or for a limited time.
- 550 9. **[Privilege Restriction](#)**: Restrict privileges based on attributes of users and system
551 elements, as well as on environmental factors.
- 552 10. **[Realignment](#)**: Structure systems and resource uses to align with mission or business
553 function needs, reduce current and anticipated risks, and accommodate the evolution of
554 technical, operational, and threat environments.
- 555 11. **[Redundancy](#)**: Provide multiple protected instances of critical resources.
- 556 12. **[Segmentation](#)**: Define and separate system elements based on criticality and
557 trustworthiness.
- 558 13. **[Substantiated Integrity](#)**: Ascertain whether critical system elements have been
559 corrupted.
- 560 14. **[Unpredictability](#)**: Make changes randomly or unpredictably.

561 The cyber resiliency techniques are described in [Appendix D](#). Each technique is characterized by
562 both the capabilities it provides and the intended consequences of using the technologies or the
563 processes it includes. The cyber resiliency techniques reflect an understanding of the threats as
564 well as the technologies, processes, and concepts related to improving cyber resiliency to
565 address the threats. The cyber resiliency engineering framework assumes that the cyber
566 resiliency techniques will be selectively applied to the architecture or design of organizational
567 mission or business functions and their supporting system resources. Since natural synergies
568 and conflicts exist among the cyber resiliency techniques, engineering trade-offs must be made.

- 569 Cyber resiliency techniques are expected to change over time as threats evolve, advances are
 570 made based on research, security practices evolve, and new ideas emerge.
- 571 Twelve of the 14 cyber resiliency techniques can be applied to either adversarial or non-
 572 adversarial threats (including both cyber-related and non-cyber-related threats). The two cyber
 573 resiliency techniques specific to adversarial threats are [Deception](#) and [Unpredictability](#). The
 574 cyber resiliency techniques are also interdependent. For example, the [Analytic Monitoring](#)
 575 technique supports [Contextual Awareness](#). The [Unpredictability](#) technique, however, is different
 576 from the other techniques in that it is always applied in conjunction with some other technique
 577 (e.g., working with the [Dynamic Positioning](#) technique to establish unpredictable times for
 578 repositioning potential targets of interest). The definitions of cyber resiliency techniques are
 579 intentionally broad to insulate the definitions from changing technologies and threats, thus
 580 limiting the need for frequent changes to the set of techniques.
- 581 To support detailed engineering analysis, multiple representative approaches to implementing
 582 each technique are identified. As illustrated in [Figure 1](#), an *implementation approach* (or, for
 583 brevity, an *approach*) is a subset of the technologies and processes included in a technique,
 584 defined by how the capabilities are implemented or how the intended outcomes are achieved.



585
 586 **FIGURE 1: CYBER RESILIENCY TECHNIQUES AND IMPLEMENTATION APPROACHES**

587 Table D-4 in [Appendix D](#) defines representative approaches and gives representative examples
588 of technologies and practices. The set of approaches for a specific technique is not exhaustive
589 and represents relatively mature technologies and practices. Thus, technologies emerging from
590 research can be characterized in terms of the techniques they apply while not being covered by
591 any of the representative approaches.²⁵

592 **2.1.4 Cyber Resiliency Design Principles**

593 A *design principle* refers to a distillation of experience designing, implementing, integrating, and
594 upgrading systems that systems engineers and architects can use to guide and inform design
595 decisions and analysis. A design principle takes the form of a terse statement or a phrase
596 identifying a key concept accompanied by one or more statements that describe how that
597 concept applies to system design (where “system” is construed broadly to include operational
598 processes and procedures and may also include development and maintenance environments).
599 Design principles are defined for many specialty engineering disciplines using the terminology,
600 experience, and research results that are specific to the specialty.

601 Cyber resiliency design principles, like design principles from other specialty disciplines, can be
602 applied in different ways at multiple stages in the system life cycle, including the operations and
603 maintenance stage. The design principles can also be used in a variety of system development
604 models, including agile and spiral development. The cyber resiliency design principles identified
605 in this publication can serve as a starting point for systems engineers and architects. For any
606 given situation, only a subset of the design principles are selected, and those principles are
607 tailored or “re-expressed” in terms more meaningful to the program, system, or system-of-
608 systems to which they apply.

609 The cyber resiliency design principles are strongly informed by and can be aligned with design
610 principles from other specialty disciplines, such as the security design principles in [\[SP 800-160
611 v1\]](#). Many of the cyber resiliency design principles are based on design principles for security,
612 resilience engineering, or both. Design principles can be characterized as *strategic* (i.e., applied
613 throughout the systems engineering process, guiding the direction of engineering analyses) or
614 *structural* (i.e., directly affecting the architecture and design of the system or system elements)
615 [\[Ricci14\]](#). Both strategic and structural cyber resiliency design principles can be reflected in
616 security-related systems engineering artifacts. A complete list of strategic and structural cyber
617 resiliency design principles is provided in [Appendix D](#).

618 **2.1.5 Relationship Among Cyber Resiliency Constructs**

619 Cyber resiliency constructs in the form of goals, objectives, techniques, implementation
620 approaches, and design principles enable systems engineers to express cyber resiliency concepts
621 and the relationships among them. In addition, the cyber resiliency constructs also relate to risk
622 management. That relationship leads systems engineers to analyze cyber resiliency solutions in
623 terms of their potential effects on risk and on specific threat events or types of malicious cyber
624 activities. The selection and relative priority of these cyber resiliency constructs is determined
625 by the organization’s strategy for managing the risks of depending on systems, which include

²⁵ Decisions about whether and how to apply less mature technologies and practices are strongly influenced by the organization’s risk management strategy. See [\[SP 800-39\]](#).

cyber resources—in particular, by the organization’s risk framing.²⁶ The relative priority of the cyber resiliency goals and objectives and relevance of the cyber resiliency design principles are determined by the risk management strategy of the organization, which takes into consideration the concerns of, constraints on, and equities of all stakeholders (including those who are not part of the organization). [Figure 2](#) illustrates the relationships among the cyber resiliency constructs. These relationships are represented by mapping tables in [Appendix D](#). As Figure 2 illustrates, a cyber-resilient system is the result of the engineering selection, prioritization, and application of cyber resiliency design principles, techniques, and implementation approaches. The risk management strategy for the organization is translated into specific interpretations and prioritizations of cyber resiliency goals and objectives, which guide and inform trade-offs among different forms of risk mitigation.

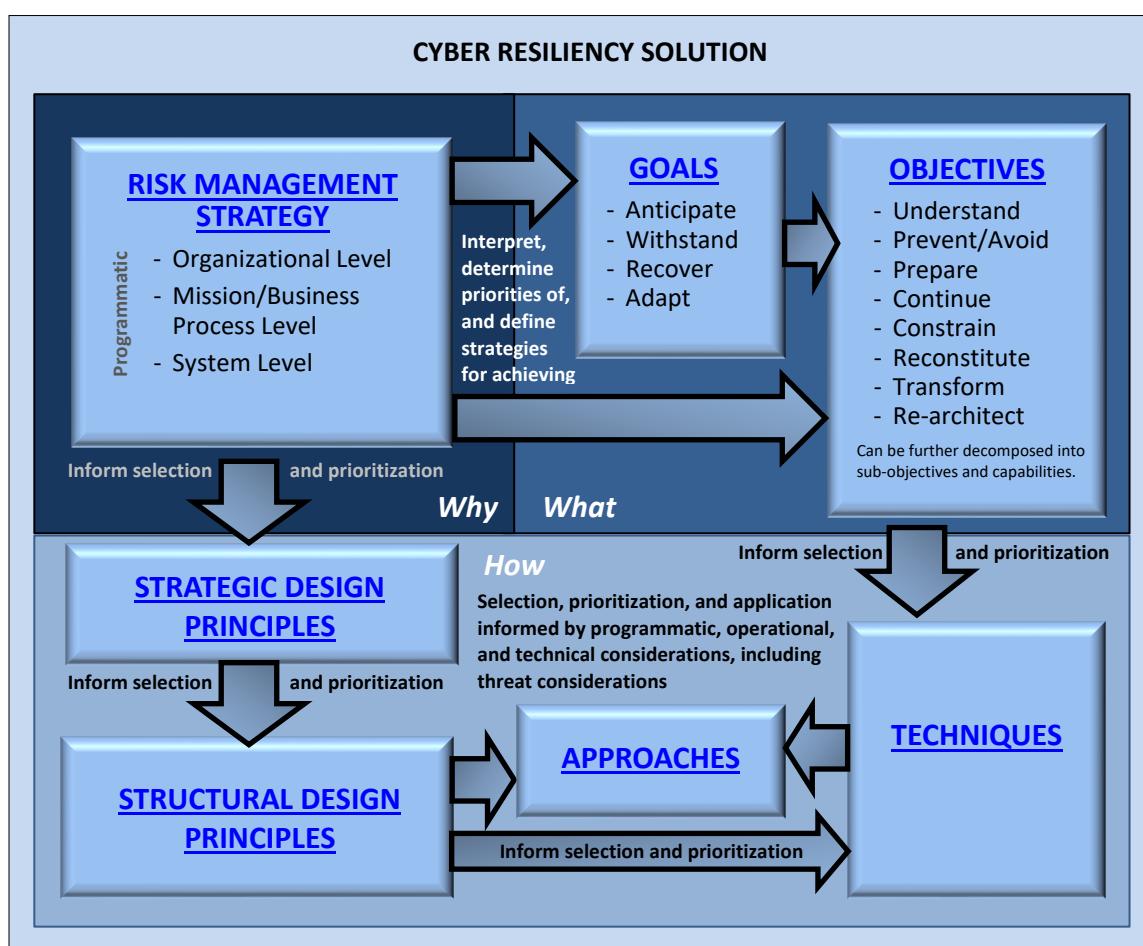


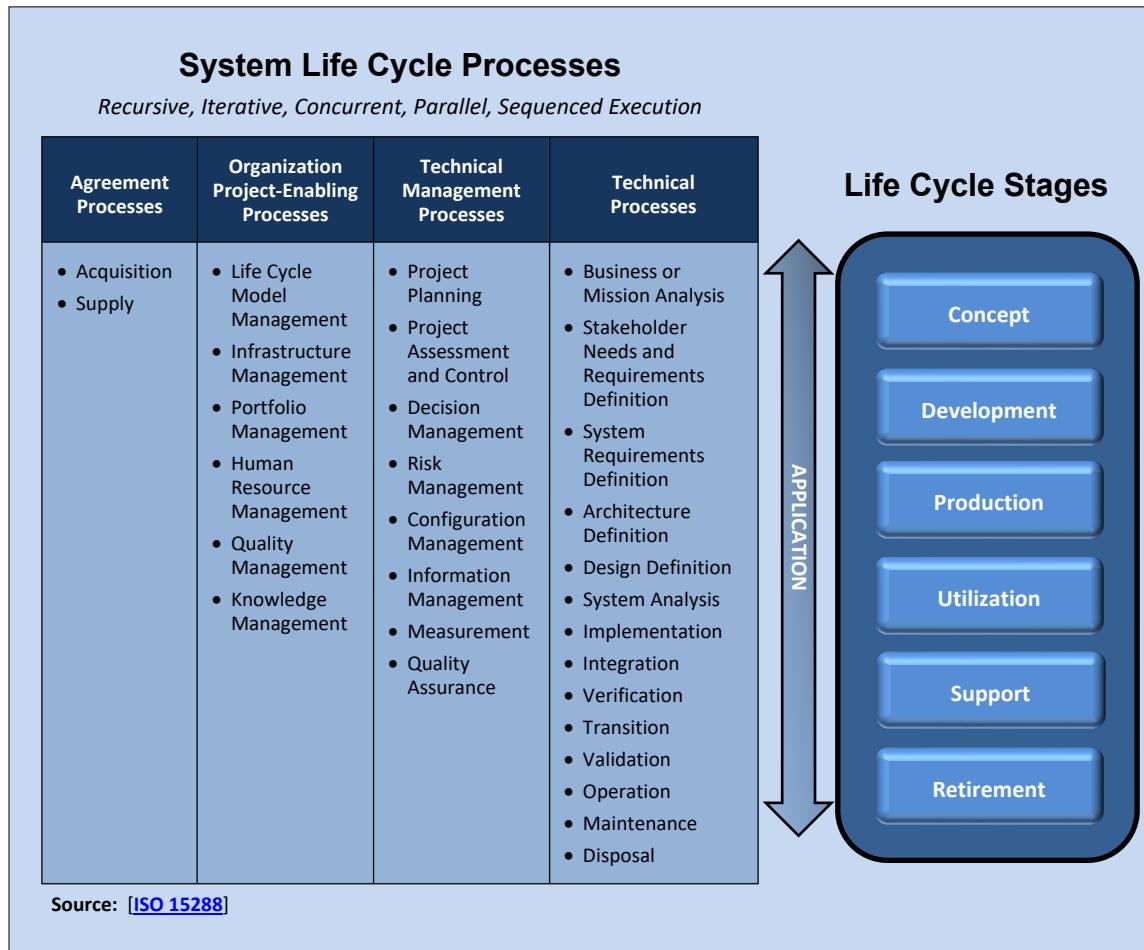
FIGURE 2: RELATIONSHIPS AMONG CYBER RESILIENCY CONSTRUCTS

²⁶ The first component of risk management addresses how organizations *frame* risk or establish a risk context—that is, describing the environment in which risk-based decisions are made. The purpose of the risk-framing component is to produce a *risk management strategy* that addresses how organizations intend to assess risk, respond to risk, and monitor risk—making explicit and transparent the risk perceptions that organizations routinely use in making both investment and operational decisions [[SP 800-39](#)]. The risk management strategy addresses how the organization manages the risks of depending on systems that include cyber resources; is part of a comprehensive, enterprise-wide risk management strategy; and reflects stakeholder concerns and priorities.

655 2.2 CYBER RESILIENCY IN THE SYSTEM LIFE CYCLE

656 The following section describes general considerations for applying cyber resiliency concepts
 657 and framework constructs to system life cycle stages and processes. Considerations include
 658 addressing the similarities and differences in security and cyber resiliency terminology and how
 659 the application of cyber resiliency goals, objectives, techniques, implementation approaches,
 660 and design principles can impact systems at key stages in the life cycle. [Figure 3](#) lists the system
 661 life cycle processes and illustrates their application across all stages of the system life cycle. It
 662 must be emphasized, however, that cyber resiliency engineering does not assume any specific
 663 life cycle or system development process, and cyber resiliency analysis can be performed at any
 664 point in and iteratively throughout the life cycle.²⁷

665



666

667

FIGURE 3: SYSTEM LIFE CYCLE PROCESSES AND LIFE CYCLE STAGES

668 Cyber resiliency constructs are interpreted and cyber resiliency engineering practices are
 669 applied in different ways, depending on the system life cycle stages. During the [Concept](#) stage,
 670 cyber resiliency goals and objectives are tailored in terms of the concept of use for the system-
 671 of-interest. Tailoring actions are used to elicit stakeholder priorities for the cyber resiliency goals

²⁷ See [Section 3.2](#).

672 and objectives. The organization's risk management strategy is used to help determine which
673 strategic design principles are most relevant. The strategic design principles and corresponding
674 structural design principles are aligned with design principles from other specialty engineering
675 disciplines. Notional or candidate system architectures are analyzed with respect to how well
676 the prioritized cyber resiliency goals and objectives can be achieved and how well the relevant
677 strategic cyber resiliency design principles can be applied. The tailoring of objectives can also be
678 used to identify or define potential metrics or measures of effectiveness for proposed cyber
679 resiliency solutions. Once again, the risk management strategy that constrains risk response or
680 risk treatment (e.g., commitment to specific technologies, requirements for interoperability with
681 or dependence on other systems) is used to help determine which techniques and approaches
682 can or cannot be used in cyber resiliency solutions. In addition, during the *Concept* stage, cyber
683 resiliency concerns for enabling systems for production, integration, validation, and supply chain
684 management are identified, and strategies for addressing those concerns are defined.

685 During the [Development](#) stage, the relevant structural cyber resiliency design principles (i.e.,
686 those principles which can be applied to the selected system architecture and which support the
687 strategic cyber resiliency design principles) are identified and prioritized based on how well the
688 design principles enable the prioritized cyber resiliency objectives to be achieved. The cyber
689 resiliency techniques and approaches indicated by the structural design principles are analyzed
690 with respect to whether and where they can be used in the selected system architecture given
691 the constraints identified earlier. Cyber resiliency solutions are defined and analyzed with
692 respect to potential effectiveness and compatibility with other aspects of trustworthiness.

693 Analysis of potential effectiveness considers the relative effectiveness of the solution against
694 potential threat events or scenarios [\[SP 800-30\]](#) and the measures of effectiveness for cyber
695 resiliency objectives. Analysis of compatibility with other aspects of trustworthiness considers
696 potential synergies or conflicts associated with technologies, design principles, or practices
697 specific to other specialty engineering disciplines, particularly security, reliability, survivability,
698 and safety. In addition, specific measures for assessing whether or not the prerequisite
699 requirements have been satisfied within the solution space are defined. This may include, for
700 example, a determination of the baseline reliability of the technology components needed to
701 deliver cyber-resilient capabilities within a system element.

702 In addition, during the [Development](#) stage, the implementation of cyber resiliency solutions is
703 analyzed and evaluated. The verification strategy for cyber resiliency solutions typically includes
704 adversarial testing or demonstration of mission or business function measures of performance
705 in a stressed environment with adversarial activities. The operational processes and procedures
706 for using technical solutions are defined, refined, and validated with respect to the ability to
707 meet mission and business objectives despite adversity involving systems containing cyber
708 resources. The cyber resiliency perspective calls for testing and other forms of validation or
709 verification that include adversarial threats among (and in combination with) other stresses on
710 the system. During this life cycle stage, resources (e.g., diverse implementations of critical
711 system elements, alternative processing facilities) required to implement specific courses of
712 action are also developed.

713 During the [Production](#) stage, the verification strategy is applied to instances or versions of the
714 system-of-interest and associated spare parts or components. The verification strategy for the
715 cyber resiliency requirements as applied to such instances and system elements includes

716 adversarial testing or demonstration in a stressed environment. In addition, during the
 717 [Production](#) stage, cyber resiliency concerns for enabling systems for production, integration,
 718 validation, and supply chain management continue to be identified and addressed.

719 During the [Utilization](#) stage, the effectiveness of cyber resiliency solutions in the operational
 720 environment is monitored. Effectiveness may decrease due to changes in the operational
 721 environment (e.g., new mission or business processes, increased user population, deployment in
 722 new locations, addition or removal of other systems or system elements with which the system-
 723 of-interest interacts), the threat environment (e.g., new threat actors, new vulnerabilities in
 724 commonly used technologies), or the technical environment (e.g., the introduction of new
 725 technologies into other systems with which the system-of-interest interacts). Cyber resiliency
 726 solutions may need to be adapted to address such changes (e.g., defining new courses of action,
 727 changing mission or business processes and procedures, reconfiguring system elements). New
 728 stakeholders may arise from changes in the operational environment, and their concerns may
 729 change the relative priorities of cyber resiliency objectives. Changes in the threat or technical
 730 environment may make some techniques or approaches less feasible, while changes in the
 731 technical or operational environment may make others more viable.

732 During the [Support](#) stage, maintenance and upgrade of the system or system elements can
 733 include integration of new cyber resiliency solutions into the system-of-interest. This stage also
 734 provides opportunities to revisit the prioritization and tailoring of cyber resiliency objectives.
 735 Upgrades to or modifications of system capabilities can include significant architectural changes
 736 that address accumulated changes to the operational, threat, and technical environments.
 737 System modifications and upgrades can also introduce additional vulnerabilities, particularly
 738 with architectural changes.

739 During the [Retirement](#) stage, system elements or the entire system-of-interest are removed
 740 from operations. The retirement process can affect other systems with which the system-of-
 741 interest interacts and can decrease the cyber resiliency of those systems and of the supported
 742 mission or business processes. Retirement strategies can include phased removal of system
 743 elements, turnkey removal of all system elements, phased replacement of system elements, and
 744 turnkey replacement of the entire system-of-interest. Cyber resiliency objectives and priorities
 745 are identified for the systems, missions, and business functions in the operational environment
 746 to inform analysis of the potential or expected effects of different retirement strategies on the
 747 ability to achieve those objectives. Like the support stage, the retirement stage can introduce
 748 significant vulnerabilities, particularly during disposal and unintended residue remaining from
 749 decommissioned assets.

750 [Table 4](#) illustrates changes in emphasis for the different cyber resiliency constructs, particularly
 751 with respect to cyber resiliency objectives (**bolded**).

752 TABLE 4: CYBER RESILIENCY IN LIFE CYCLE STAGES

| LIFE CYCLE STAGES | ROLE OF CYBER RESILIENCY CONSTRUCTS |
|-------------------|--|
| CONCEPT | <ul style="list-style-type: none"> - Prioritize and tailor objectives. - Prioritize design principles and align with other disciplines. - Limit the set of techniques and approaches to use in solutions. |

| LIFE CYCLE STAGES | ROLE OF CYBER RESILIENCY CONSTRUCTS |
|-------------------|---|
| DEVELOPMENT | <ul style="list-style-type: none"> - Apply design principles to analyze and shape architecture and design. - Use techniques and approaches to define alternative solutions. - Develop capabilities to achieve the Prevent/Avoid, Continue, Constrain, Reconstitute, and Understand objectives. |
| PRODUCTION | <ul style="list-style-type: none"> - Implement and evaluate the effectiveness of cyber resiliency solutions. - Provide resources (or ensure that resources will be provided) to achieve the Prepare objective. |
| UTILIZATION | <ul style="list-style-type: none"> - Monitor the effectiveness of cyber resiliency solutions using capabilities to achieve Understand and Prepare objectives. - Reprioritize and tailor objectives as needed, and adapt mission, business, and/or security processes to address environmental changes (Transform objective). |
| SUPPORT | <ul style="list-style-type: none"> - Revisit the prioritization and tailoring of objectives; use the results of monitoring to identify new or modified requirements. - Revisit constraints on techniques and approaches. - Modify or upgrade capabilities consistent with changes as noted (Re-Architect objective). |
| RETIREMENT | <ul style="list-style-type: none"> - Prioritize and tailor objectives for the environment of operation. - Ensure that disposal processes enable those objectives to be achieved, modifying or upgrading capabilities of other systems as necessary (Re-Architect objective). |

753

754

2.3 RISK MANAGEMENT AND CYBER RESILIENCY

755 Organizations manage the missions, business functions, and operational risks related to a
 756 dependence on systems that include cyber resources as part of a larger portfolio of risks,²⁸
 757 including financial and reputational risks; programmatic or project-related risks associated with
 758 developing a system (e.g., cost, schedule, performance); security risks associated with the
 759 organization's mission or business activities, information the organization processes or handles,
 760 or requirements arising from legislation, regulations, policies, or standards; and cybersecurity
 761 risks. A proposed cyber resiliency solution, while intended primarily to reduce mission, business,
 762 or operational risk, can also reduce other types of risk (e.g., security risk, reputational risk,
 763 supply chain risk, performance risk). However, like any solution to a risk management problem,
 764 it can also increase other types of risk (e.g., financial, cost, or schedule risk). As part of a
 765 multidisciplinary systems engineering effort, systems security engineers and risk management
 766 professionals are responsible for articulating the potential risk impacts of alternative solutions,
 767 determining whether those impacts fall within the organizational risk tolerance, deciding
 768 whether the adoption of a proposed solution is consistent with the organization's risk
 769 management strategy, and informing the organization's risk executive (function) of risk trade-
 770 offs.²⁹

²⁸ These risks are typically addressed by organizations as part of an Enterprise Risk Management (ERM) program. See [IR 8286].

²⁹ See [Section 3.2.1](#) and [Section C.4](#).

771 At the organizational level, a cyber resiliency perspective on risk management can lead to
772 analysis of and management of risks associated with programs and initiatives at multiple levels,
773 which involve investment in, transition to, use of, or transition away from different cyber
774 technologies. The environment in which a system-of-interest is engineered is rarely static.
775 Related programs, initiatives, or other efforts can include programs at federal agencies to
776 transition to a zero trust architecture, initiatives to reduce software supply chain risks driven by
777 [EO 14028], and initiatives to transition to IPv6 and away from IPv4. Such organization-level
778 programs and initiatives can affect the execution of efforts at lower levels (e.g., an acquisition
779 program for a specific system or service, an initiative to redefine a mission or business process
780 to better accommodate telework).

781 Motivated by the cyber resiliency [Adapt](#) goal, an organization's risk management strategy can
782 call for the analysis of questions such as:

- 783 • How does each step in a transition plan or an investment plan change the attack surface?
- 784 • Are new attack vectors enabled by a given step? How will they be mitigated? Will they be
785 removed in a later step?
- 786 • Does this step increase fragility, complexity, or instability, and if so, how will those risks be
787 managed?
- 788 • On what other programs or initiatives does this step depend, and how will the risks that
789 those efforts will not achieve the expected objectives be managed?
- 790 • What new or modified operational procedures and processes are assumed, and how will
791 they be resourced and staffed?
- 792 • What policy or governance changes are assumed? How will they be achieved? What risks
793 would result if they are not achieved?
- 794 • How will the cyber resiliency objectives (as interpreted and prioritized by the organization)
795 continue to be achieved in the face of changes resulting from different programs and
796 initiatives?

797
798

GENERALIZED CYBER RESILIENCY CONSTRUCTS

The definitions of the cyber resiliency goals, objectives, and techniques are generally defined so that they can be applied to all types of threats (not solely cyber threats) and all types of systems (not solely systems that include or are enabled by cyber resources). However, the motivation for these definitions and for the selection of objectives and techniques for inclusion in the cyber resiliency engineering framework is the recognition of dependence on systems involving cyber resources in a threat environment that includes the APT.

799

800 CHAPTER THREE

801 CYBER RESILIENCY IN PRACTICE

802 APPLYING CYBER RESILIENCY CONCEPTS, CONSTRUCTS, PRACTICES

803 This chapter identifies considerations for determining which cyber resiliency constructs are
804 most relevant to a system-of-interest and describes a tailororable process for applying cyber
805 resiliency concepts, constructs, and practices to a system. It also includes guidance on the
806 cyber resiliency analysis carried out during the system life cycle to determine whether the cyber
807 resiliency properties and behaviors of a system-of-interest, regardless of its life cycle stage, are
808 sufficient for the organization using that system to meet its mission assurance, business
809 continuity, or other security requirements in a threat environment and contested cyberspace
810 that includes the APT.

811 3.1 SELECTING AND PRIORITIZING CYBER RESILIENCY CONSTRUCTS

812 The variety of concerns, technologies, and practices related to cyber resiliency results in an
813 extensive framework for cyber resiliency engineering. For example, the engineering framework
814 identifies 14 cyber resiliency techniques and 50 cyber resiliency implementation approaches.
815 The engineering framework is also complex, with relationships among the constructs of goals,
816 objectives, design principles, techniques, and approaches as discussed in [Appendix D](#). Cyber
817 resiliency design principles, techniques, and approaches build on, complement, or function in
818 synergy with mechanisms intended to ensure other quality properties (e.g., security, safety, and
819 system resilience).

820 The variety of circumstances and types of systems for which cyber resiliency can be applied
821 means that no single cyber resiliency technique, approach, or set of approaches is universally
822 optimal or applicable. Systems security engineering seeks to manage risk rather than provide a
823 universal solution. The choice of a risk-appropriate set of cyber resiliency techniques and
824 approaches depends on various trade space considerations and risk factors that are assessed
825 during the systems engineering processes. Employing all cyber resiliency techniques and
826 approaches is not needed to achieve the cyber resiliency objectives prioritized by stakeholders.
827 In fact, it is not possible to employ all techniques and approaches simultaneously. The following
828 subsections describe factors to consider when selecting a set of cyber resiliency techniques and
829 implementation approaches that best fits the system-of-interest.

830 3.1.1 Achievement of Goals and Objectives

831 Cyber resiliency techniques and associated implementation approaches are employed to
832 achieve mission or business objectives. The relative priorities of cyber resiliency goals and
833 objectives are determined by the mission or business objectives. The selection of specific cyber
834 resiliency techniques and approaches is therefore driven in part by the relative priorities of the
835 objectives they support.³⁰

³⁰ See [Appendix D, Table D-13](#).

836 **3.1.2 Cyber Risk Management Strategy**

837 An organization's cyber risk management strategy (i.e., its strategy for managing risks stemming
838 from dependencies on systems which include cyber resources) is part of its risk management
839 strategy and includes its risk framing for cyber risks.³¹ The organization's risk frame identifies
840 which risks or risk factors (i.e., potential impacts or consequences) are unacceptable. For cyber
841 resiliency, the risk frame assumes an advanced adversary with a persistent presence in
842 organizational systems. The risk response portion of the risk management strategy can include
843 priorities or preferences for the types of effects on adversary activities³² to seek in cyber
844 resiliency solutions.

845 An organization's risk management strategy is constrained by such factors as legal, regulatory,
846 and contractual requirements as reflected in organizational policies and procedures; financial
847 resources; legacy investments; and organizational culture. These constraints can be reflected in
848 the selection and tailoring of cyber resiliency techniques, approaches, and design principles. For
849 example, organizational policies and culture can strongly influence whether and how the cyber
850 resiliency technique of [Deception](#) is used. The risk management strategy can define an order of
851 precedence for responding to identified risks analogous to the safety order of precedence, such
852 as "harden, sensor, isolate, obfuscate." Together with the strategic design principles selected
853 and specifically tailored to a given program, mission, business function, or system, the order of
854 precedence can guide the selection and application of structural design principles at different
855 locations in an architecture.³³

856 **3.1.3 System Type**

857 The set of cyber resiliency techniques and approaches which are most relevant to and useful in a
858 system depends on the type of system. The following present some general examples of system
859 types and examples of techniques and approaches that might be appropriate for those types of
860 systems. Additional (more specific) examples are provided at the SP 800-160, Volume 2 website.
861 In addition to the techniques and approaches listed in the examples below, there may be other
862 techniques and approaches that could be useful for a particular type of system. The specific
863 aspects of the system in question will impact the selection as well.

864 • **Enterprise IT Systems, Shared Services, and Common Infrastructures**

865 Enterprise IT (EIT) systems are typically general-purpose computing systems—very often
866 with significant processing, storage, and bandwidth—capable of delivering information
867 resources which can meet the business or other mission needs of an enterprise or a large
868 stakeholder community. As such, all of the cyber resiliency techniques and associated
869 approaches may potentially be viable, although their selection would depend on the other
870 considerations noted in this section.

³¹ Risk management consists of four major components: risk framing, risk assessment, risk response, and risk monitoring [[SP 800-39](#)]. Security risks are considered throughout an organization's enterprise risk management (ERM) process. This includes identifying the risk context; identifying, analyzing, and prioritizing risks; planning and executing risk response strategies; and monitoring, evaluating, and adjusting risk [[IR 8286](#)]. Risk response is also referred to as risk treatment [[SP 800-160 v1](#)] [[ISO 73](#)]. Organizational risk tolerance is determined as part of the risk framing component and defined in the risk management strategy [[SP 800-39](#)].

³² See [Appendix F](#).

³³ See [Appendix D](#).

871 • **Large-Scale Processing Environments**

872 Large scale processing environments (LSPEs) handle large numbers of events (e.g., process
873 transactions) with high confidence in service delivery. The scale of such systems makes them
874 highly sensitive to disruptions to or degradation of service. Therefore, the selective use of
875 the [Offloading](#) and [Restriction](#) implementations approaches can make the scale of such
876 systems more manageable. This, in turn, will support the application of [Analytic Monitoring](#)
877 and the [Mission Dependency and Status Visualization](#) approach to [Contextual Awareness](#) in
878 a manner that does not significantly affect performance. LSPEs often implement [Dynamic](#)
879 [Positioning](#) functionality that can be repurposed to help improve cyber resiliency via the
880 [Functional Relocation of Cyber Resources](#), [Fragmentation](#), and [Distributed Functionality](#)
881 approaches.

882 • **System-of-Systems**

883 Many cyber resiliency techniques are likely to be applicable to a system-of-systems, but
884 some techniques and approaches can offer greater benefits than others. For example,
885 [Contextual Awareness](#) implemented via [Mission Dependency and Status Visualization](#) can be
886 applied to predict the potential mission impacts of cyber effects of adversary activities on
887 constituent systems or system elements. The [Calibrated Defense-in-Depth](#) and [Consistency](#)
888 [Analysis](#) approaches to the technique of [Coordinated Protection](#) can help ensure that the
889 disparate protections of the constituent systems operate consistently and in a coordinated
890 manner to prevent or delay the advance of an adversary across those systems. For a system-
891 of-systems involving constituent systems that were not designed to work together and that
892 were developed with different missions, functions, and risk frames, [Realignment](#) could also
893 be beneficial. In particular, the [Offloading](#) and [Restriction](#) approaches could be used to
894 ensure that the core system elements are appropriately aligned to the overall system-of-
895 system mission.

896 • **Critical Infrastructure Systems**

897 Critical infrastructure systems are often specialized, high-confidence, dedicated, purpose-
898 built systems that have highly deterministic properties. Therefore, the availability and
899 integrity of the functionality of the systems are very important as the corruption or lack of
900 availability of some of the key system elements could result in significant harm. For these
901 reasons, techniques adapted from system resilience, such as [Redundancy](#) (particularly the
902 [Protected Backup and Restore](#) and [Surplus Capacity](#) approaches) coupled with aspects of
903 [Diversity](#) (e.g., [Architectural Diversity](#), [Supply Chain Diversity](#)), could prevent attacks from
904 having mission or business consequences and also maximize the chance of continuation of
905 the critical or essential mission or business operations. [Segmentation](#) can isolate highly
906 critical system elements to protect them from an adversary's activities. Approaches such as
907 [Trust-Based Privilege Management](#) and [Attribute-Based Usage Restriction](#) could constrain
908 the potential damage that an adversary could inflict on a system.

909 • **Cyber-Physical Systems**

910 As with critical infrastructure systems, cyber-physical systems (CPS) often have significant
911 limitations regarding storage capacity, processing capabilities, and bandwidth. In addition,
912 many of these systems have a high degree of autonomy with limited human interaction.
913 Some cyber-physical systems operate with no active network connection, although they
914 may connect to a network under specific circumstances (e.g., scheduled maintenance). [Non-](#)

915 [Persistent Services](#) support the periodic refreshing of software and firmware from a trusted
916 source (e.g., an offline redundant component), in effect flushing out any malware. However,
917 that approach applies only if the organization can allow for the periodic downtime that the
918 refresh would entail. Similarly, the [Integrity Checks](#) approach to [Substantiated Integrity](#)
919 implemented via cryptographic checksums on critical software could help enable embedded
920 systems to detect corrupted software components.

921 • **Internet of Things**

922 An Internet of Things (IoT) system consists of system elements with network connectivity,
923 which communicate with an Internet-accessible software application. That software
924 application, which is part of the IoT system, orchestrates the behavior of or aggregates the
925 data provided by constituent system elements. As in a cyber-physical system, the system
926 elements have limitations in the areas of power consumption, processing, storage capacity,
927 and bandwidth, which in turn may limit the potential for such processing-intensive cyber
928 resiliency approaches as [Obfuscation](#) or [Adaptive Management](#) at the device level. Because
929 many “things” (e.g., light bulbs, door locks) are small and relatively simple, they often lack
930 the capacity for basic protection. However, the [Integrity Checks](#) approach to [Substantiated](#)
931 [Integrity](#) could still be viable, applied in conjunction with reliability mechanisms. An IoT
932 system assumes Internet connectivity, although the set of “things” are usually capable of
933 functioning independently if not connected. Because many IoT systems do not assume
934 technical expertise on the part of users, cyber resiliency techniques and approaches that
935 involve human interaction (e.g., [Disinformation](#), [Misdirection](#)) may not be appropriate. In
936 addition, the design of IoT systems accommodates flexibility and repurposing of the
937 capabilities of constituent “things.” Thus, an application that orchestrated the behavior of
938 one set of “things” may be upgraded to orchestrate additional sets, the members of which
939 were not designed with that application in mind. Such changes to the IoT systems to which
940 that application or the additional sets originally belong can benefit from the application of
941 [Realignment](#). At the level of an IoT system (rather than at the level of individual system
942 elements), [Segmentation](#) and [Consistency Analysis](#) can be applied.

943 **3.1.4 Cyber Resiliency Conflicts and Synergies**

944 Cyber resiliency techniques can interact in several ways. One technique can depend on another
945 so that the first cannot be implemented without the second; for example, [Adaptive Response](#)
946 depends on [Analytic Monitoring](#) or [Contextual Awareness](#) since a response requires a stimulus.
947 One technique can support another, making the second more effective; for example, [Diversity](#)
948 and [Redundancy](#) are mutually supportive. One technique can use another so that more design
949 options are available than if the techniques were applied independently; for example, [Analytic](#)
950 [Monitoring](#) can use [Diversity](#) in a design, which includes a diverse set of monitoring tools.

951 However, one technique can also conflict with or complicate the use of another. For example,
952 [Diversity](#) and [Segmentation](#) can each make [Analytic Monitoring](#) and [Contextual Awareness](#) more
953 difficult; a design that incorporates [Diversity](#) requires monitoring tools that can handle the
954 diverse set of system elements, while implementation of [Segmentation](#) can limit the visibility of
955 such tools. In selecting techniques in accordance with the risk management strategy and design
956 principles, synergies and conflicts between various techniques are taken into consideration. The
957 text below offers three illustrative examples of the interplay, focusing on the techniques that
958 increase an adversary’s work factor.

959 As a first example, [Dynamic Positioning](#) and [Non-Persistence](#) enable operational agility by
960 making it more difficult for an adversary to target critical resources. These techniques support
961 the [Continue](#), [Constrain](#), and [Reconstitute](#) objectives and are part of applying the [Support agility](#)
962 [and architect for adaptability](#) strategic design principle and the [Change or disrupt the attack](#)
963 [surface](#) structural design principle. At the same time, these techniques (and the associated
964 implementation approaches) also make it more difficult for an organization to maintain
965 situational awareness of its security posture. That is, [Dynamic Positioning](#) and [Non-Persistence](#)
966 complicate the use of [Contextual Awareness](#) and aspects of [Analytic Monitoring](#), and thus can
967 conflict with the [Maintain situational awareness](#) structural design principle.

968 As a second example, [Redundancy](#) and [Diversity](#) together are effective at resisting adversary
969 attacks. These techniques enhance the system's ability to achieve the [Continue](#) and [Reconstitute](#)
970 objectives and apply the [Plan and manage diversity](#) and [Maintain redundancy](#) structural design
971 principles. However, the implementation of both [Redundancy](#) and [Diversity](#) will increase the
972 system's attack surface.

973 As a final example, [Deception](#) can lead the adversary to waste effort and reveal tactics,
974 techniques, and procedures (TTP), but it can also complicate the use of aspects of [Analytic](#)
975 [Monitoring](#) and [Contextual Awareness](#). In general, while [Redundancy](#), [Diversity](#), [Deception](#),
976 [Dynamic Positioning](#), and [Unpredictability](#) will likely greatly increase the adversary work factor,
977 they come at a cost to some other cyber resiliency objectives, techniques, and design principles.

978 No technique or set of techniques is optimal with respect to all decision factors. There are
979 always ramifications for employing any given technique. The determination of the appropriate
980 selection of techniques is a trade decision that systems engineers make. A more complete
981 identification of potential interactions (e.g., synergies and conflicts) between cyber resiliency
982 techniques is presented in [Table D-3](#).

983 **3.1.5 Other Disciplines and Existing Investments**

984 Many of the techniques and implementation approaches supporting cyber resiliency are well-
985 established. Some technologies or processes are drawn from other disciplines (e.g., Continuity
986 of Operations [COOP], cybersecurity) but are used or executed in a different manner to support
987 cyber resiliency. These include [Adaptive Response](#), [Analytic Monitoring](#), [Coordinated Protection](#),
988 [Privilege Restriction](#), [Redundancy](#), and [Segmentation](#). Others are drawn from disciplines that
989 deal with non-adversarial threats (e.g., safety, reliability, survivability). These include [Contextual](#)
990 [Awareness](#), [Diversity](#), [Non-Persistence](#), [Realignment](#), and [Substantiated Integrity](#). Still others are
991 cyber adaptations of non-cyber concepts drawn from disciplines that deal with adversarial
992 threats (e.g., medicine, military, sports). These include [Deception](#), [Dynamic Positioning](#), and
993 [Unpredictability](#). Legacy investments made by an organization in these other disciplines can
994 influence which cyber resiliency techniques and approaches are most appropriate to pursue.

995 **3.1.5.1 Investments from Cybersecurity, COOP, and Resilience Engineering**

996 Redundancy-supporting approaches—such as backup, surplus capacity, and replication—are
997 well-established in COOP programs. From a cyber resiliency perspective, however, these
998 approaches are not sufficient to protect against the APT. A threat actor might choose to target
999 backup servers as optimum locations to implant malware if those servers are not sufficiently
1000 protected. In addition, remote backup servers that employ the same architecture as the primary

1001 server are vulnerable to malware that has compromised the primary server. However, if an
1002 organization has already invested in backup services (in support of COOP or cybersecurity),
1003 those services can be enhanced by requiring an adversary to navigate multiple distinct defenses,
1004 authentication challenges ([Calibrated Defense-in-Depth](#) approach to [Coordinated Protection](#)), or
1005 some form of [Synthetic Diversity](#) to compensate for known attack vectors.

1006 [Contextual Awareness](#) and [Analytic Monitoring](#) capabilities are often provided by performance
1007 management and cybersecurity functions, including cyber situational awareness, anomaly
1008 detection, and performance monitoring. However, the off-the-shelf implementations of these
1009 functions are generally insufficient to detect threats from advanced adversaries. Enhancing
1010 existing investments in both detection and monitoring by integrating data from sensor and
1011 monitor readings from disparate sources is a way to take these existing investments and make
1012 them an effective cyber resiliency tool. Another way to make existing technology more cyber-
1013 resilient is to complement the existing monitoring services with information from threat
1014 intelligence sources, enabling these tools to be better-tuned to look for known observables
1015 (e.g., indicators of adversary TTPs).

1016 Some approaches to [Segmentation](#) and [Coordinated Protection](#) appear in information security
1017 or cybersecurity. [Predefined Segmentation](#), as reflected in boundary demilitarized zones
1018 (DMZs), is a well-established construct in cybersecurity. One important distinction of cyber
1019 resiliency is that the segmentation is applied throughout the system, not just at the system
1020 boundary. In addition, the [Dynamic Segmentation and Isolation](#) approach allows for changing
1021 the placement and/or activation of the protected segments. For [Coordinated Protection](#), the
1022 defense-in-depth approach is often used for security or system resilience. Ensuring that those
1023 protections work in a coordinated fashion is one of the distinguishing aspects of cyber resiliency.

1024 **3.1.5.2 Investments from Non-Adversarial Disciplines**

1025 Some cyber resiliency techniques and approaches come from disciplines such as safety or
1026 performance management. [Diversity](#) and certain implementations of [Substantiated Integrity](#),
1027 such as Byzantine quorum systems³⁴ or checksums on critical software, can be traced back to
1028 the safety discipline.³⁵ Therefore, systems that have been designed with safety in mind may
1029 already have implemented some of these capabilities. However, the safety capabilities were
1030 designed with the assumption that they were countering non-adversarial threat events. To
1031 make these capabilities useful against the APT, certain changes are needed. From a safety
1032 perspective, it may be sufficient to only employ polynomial hashes on critical software to ensure
1033 that the software has not been corrupted over time. However, such hashes are not sufficient
1034 when dealing with the APT, which is able to corrupt the software and data and then recalculate
1035 the checksum. Instead, what is needed in those instances are cryptographic-based polynomial
1036 checksums.

1037 Other capabilities such as [Non-Persistence](#) and [Adaptive Response](#) are very common in cloud
1038 and virtualization architectures. Again, these capabilities were not designed or employed to

³⁴ The National Aeronautics and Space Administration (NASA) Space Shuttle Program applied this concept in multiple computers, which would vote on certain maneuvers.

³⁵ This is an example of *operational redundancy* where specific failure modes are managed as part of the nominal operation of the system. Redundant Array of Independent Disks (RAID) storage systems and “hyper-converged” computing architectures (i.e., those relying on erasure code for distributed data stores) also fall into this category.

1039 specifically counter the APT but to facilitate rapid deployment of implementations. From a
1040 system design and implementation perspective, it is most likely easier to employ existing
1041 virtualization technology and change the criteria of when and why to refresh critical services
1042 (e.g., periodically refresh the software and firmware with the goal of flushing out malware) than
1043 it is to deploy [Non-Persistence](#) in a system that cannot implement the capability.

1044 **3.1.5.3 Investments from Adversarial Disciplines**

1045 Several of the cyber resiliency techniques and approaches are cyber adaptions of non-cyber
1046 methods used in adversary-oriented disciplines (e.g., medicine, military, sports). These include
1047 the [Deception](#), [Unpredictability](#), and [Dynamic Positioning](#) techniques and the [Dynamic Threat](#)
1048 [Awareness](#) and [Evolvability](#) approaches. None of those techniques or approaches are employed
1049 in non-adversarial disciplines. There is no reason in resilience engineering to attempt to
1050 “mislead” a hurricane, nor is there any benefit in safety engineering to include an element of
1051 unpredictability. The value of these constructs in non-cyber environments is well established.
1052 Because these adversarial-derived techniques and approaches are not typically found in
1053 disciplines such as safety, resilience engineering, or COOP, it is much more challenging to
1054 provide them by enhancing existing constructs. Therefore, they may be more challenging to
1055 integrate into an existing system.

1056 **3.1.6 Architectural Locations**

1057 The selection of cyber resiliency techniques or approaches depends, in part, on where (i.e., at
1058 what layers, in which components or system elements, at which interfaces between layers or
1059 between system elements) in the system architecture cyber resiliency solutions can be applied.
1060 The set of layers, like the set of system components or system elements, in an architecture
1061 depends on the type of system. For example, an embedded system offers a different set of
1062 possible locations than an enterprise architecture that includes applications running in a cloud.
1063 The set of possible layers can include, for example, an operational (people-and-processes) layer,
1064 a support layer, and a layer to represent the physical environment.

1065 Different cyber resiliency techniques or approaches lend themselves to implementation at
1066 different architectural layers.³⁶ Some approaches can be implemented at multiple layers, in
1067 different ways, and with varying degrees of maturity. Other approaches are highly specific to a
1068 layer; for example, [Asset Mobility](#) is implemented in the operations layer or in the physical
1069 environment. For some layers, many approaches may be applicable; for others, relatively few
1070 approaches may be available. For example, relatively few approaches can be implemented at
1071 the hardware layer. These include [Dynamic Reconfiguration](#), [Architectural Diversity](#), [Design](#)
1072 [Diversity](#), [Replication](#), [Predefined Segmentation](#), and [Integrity Checks](#).

1073 Similarly, some cyber resiliency approaches lend themselves to specific types of components or
1074 system elements. For example, [Fragmentation](#) applies to information stores. Some approaches
1075 assume that a system element or set of system elements has been included in the architecture
1076 specifically to support cyber defense. These include [Dynamic Threat Awareness](#), [Forensic and](#)
1077 [Behavioral Analysis](#), and [Misdirection](#). Other cyber resiliency approaches assume that a system
1078 element has been included in the architecture, explicitly or virtually, to support the mission,

³⁶ See [Appendix D, Table D-4](#).

1079 security, or business operations. These include [Sensor Fusion and Analysis](#), [Consistency Analysis](#),
1080 [Orchestration](#), and all of the approaches to [Privilege Restriction](#).

1081 Finally, some techniques or approaches lend themselves to implementation at interfaces
1082 between layers or between system elements. These include [Segmentation](#), [Monitoring and](#)
1083 [Damage Assessment](#), and [Behavior Validation](#).

1084 **3.1.7 Effects on Adversaries, Threats, and Risks**

1085 The selection of cyber resiliency techniques and approaches can be motivated by potential
1086 effects on adversary activities or on risk. Two resiliency techniques or approaches listed as both
1087 potentially having the same effect may differ in how strongly that effect applies to a given threat
1088 event, scope (i.e., the set of threat events for which the effect is or can be produced), and
1089 affected risk factors. For example, all approaches to [Non-Persistence](#) can degrade an adversary's
1090 ability to maintain a covert presence via the malicious browser extension TTP; closing the
1091 browser session when it is no longer needed, a use of [Non-Persistent Services](#), degrades the
1092 adversary's activity more than do the other [Non-Persistence](#) approaches. Some techniques or
1093 approaches will affect more risk factors (e.g., reduce the likelihood of impact or reduce the level
1094 of impact) than others. The security mechanisms or processes used to implement a particular
1095 cyber resiliency approach will also vary with respect to their scope and strength. For example, a
1096 [Misdirection](#) approach to the [Deception](#) technique, implemented via a deception net, and the
1097 [Sensor Fusion and Analysis](#) approach to [Analytic Monitoring](#), implemented via a holistic suite of
1098 intrusion detection systems, will both achieve the detect effect. However, the effectiveness and
1099 scope of the two vary widely. For this reason, engineering trade-offs among techniques,
1100 approaches, and implementations should consider the actual effects to be expected in the
1101 context of the system's architecture, design, and operational environment.

1102 In general, systems security engineering decisions seek to provide as complete a set of effects as
1103 possible and to maximize those effects with the recognition that this optimization problem will
1104 not have a single solution. The rationale for selecting cyber resiliency techniques or approaches
1105 that have complete coverage of the potential effects relates to the long-term nature of the
1106 threat campaigns. Potentially, engagements with the APT may go on for months, if not years,
1107 possibly starting while a system is in development or even earlier in the life cycle. Given the
1108 nature of the threat, its attacks will likely evolve over time in response to a defender's actions.
1109 Having a selection of techniques and approaches—where each technique and approach
1110 supports (to different degrees and in different ways) multiple effects on the adversary, and the
1111 union of the techniques and approaches allows for all potential effects on an adversary—
1112 provides the systems engineers with the flexibility to evolve and tailor the effects to the
1113 adversary's changing actions. This is analogous to team sports where a team will change its
1114 game plan in response to player injuries and the changing game plan of the other team. A team
1115 with players who can play multiple positions gives it the flexibility to respond to changes by the
1116 opposition and to potentially replace injured players.

1117 Different cyber resiliency techniques and approaches can have different effects on threat events
1118 and risk. No single technique or approach can create all possible effects on a threat event, and
1119 no technique or approach or set of techniques or approaches can eliminate risk. However, by

1120 considering the desired effects, systems engineers can select a set of techniques that will
1121 collectively achieve those effects.³⁷

1122 **3.1.8 Maturity and Potential Adoption**

1123 Approaches to applying cyber resiliency techniques vary in maturity and adoption. The decision
1124 to use less mature technologies depends on the organization’s risk management strategy and its
1125 strategy for managing technical risks. Many highly mature and widely adopted technologies and
1126 processes that were developed to meet the general needs of performance, dependability, or
1127 security can be used or repurposed to address cyber resiliency concerns. These pose little, if any,
1128 technical risk. Changes in operational processes, procedures, and configuration changes may be
1129 needed to make these technologies and processes effective against the APT and thus part of
1130 cyber resiliency solutions.

1131 A growing number of technologies are specifically oriented toward cyber resiliency, including
1132 moving target defenses and deception toolkits. These technologies are currently focused on
1133 enterprise IT environments. As these technologies become more widely adopted, the decision
1134 to include the technologies is influenced more by policy than by technical risk considerations.
1135 This is particularly the case for applications of the [Deception](#) and [Unpredictability](#) cyber
1136 resiliency techniques.

1137 Cyber resiliency is an active research area. Technologies are being explored to improve the
1138 cyber resiliency of cyber-physical systems, high-confidence dedicated-purpose systems, and
1139 large-scale processing environments. The integration of solutions involving new technologies to
1140 reduce risks due to the APT should be balanced against risks associated with perturbing such
1141 systems.

1142 **3.2 ANALYTIC PRACTICES AND PROCESSES**

1143 In the context of systems security engineering, cyber resiliency analysis is intended to determine
1144 whether the cyber resiliency properties and behaviors of a system-of-interest, regardless of its
1145 system life cycle stage, are sufficient for the organization using that system to meet its mission
1146 assurance, business continuity, or other security requirements in a threat environment that
1147 includes the APT. Cyber resiliency analysis is performed with the expectation that such analysis
1148 will support systems engineering and risk management decisions about the system-of-interest.
1149 Depending on the life cycle stage, programmatic considerations, and other factors discussed
1150 above, a cyber resiliency analysis could recommend architectural changes, the integration of
1151 new products or technologies into the system, changes in how existing products or technologies
1152 are used, or changes in operating procedures or environmental protections consistent with and
1153 designed to implement the organization’s risk management strategy.

1154 The following subsections describe a general, tailororable process for cyber resiliency analysis
1155 consisting of steps and tasks, as summarized in [Table 5](#). A variety of motivations for a cyber
1156 resiliency analysis are possible, including ensuring that cyber risks due to the APT are fully
1157 considered as part of the RMF process or other risk management process, supporting systems
1158 security engineering tasks, and recalibrating assessments of risk and risk responses based on
1159 information about new threats (e.g., information about a cyber incident or an APT actor), newly

³⁷ See [Appendix F](#).

- 1160 discovered vulnerabilities (e.g., discovery of a common design flaw), and problematic
 1161 dependencies (e.g., discovery of a supply chain issue). Although described in terms of a broad
 1162 analytic scope, the process can be tailored to have a narrow scope, such as analyzing the
 1163 potential cyber resiliency improvement that could be achieved by integrating a specific
 1164 technology or identifying ways to ensure adequate cyber resiliency against a specific threat
 1165 scenario.
- 1166 The analytic processes and practices related to cyber resiliency are intended to be integrated
 1167 with those for other specialty engineering disciplines, including security, systems engineering,
 1168 resilience engineering, safety, cybersecurity, and mission assurance.³⁸ In addition, analytic
 1169 processes and practices related to cyber resiliency can leverage system representations offered
 1170 by model-based systems engineering (MBSE) and analytic methods (including those involving
 1171 artificial intelligence [AI] and machine learning [ML]) integrated into MBSE.
- 1172 A variety of artifacts can provide information used in a cyber resiliency analysis depending on its
 1173 scope, the life cycle stage of the system or systems within the scope of the analysis, the step in
 1174 the RMF of the in-scope system or systems, the extent to which the organization relying on the
 1175 system or systems has done contingency planning, and (for systems in the Utilization life cycle
 1176 stage) reports on security posture and incident response. These artifacts can include engineering
 1177 project plans, system security plans, supply chain risk management plans [[SP 800-161](#)], reports
 1178 on security posture [[SP 800-37](#)], penetration test results, contingency plans [[SP 800-34](#)], risk
 1179 analyses [[SP 800-30](#)], after-action reports from exercises, incident reports, and recovery plans.
- 1180 Cyber resiliency analysis complements both system life cycle and RMF tasks. The life cycle and
 1181 RMF tasks produce information that can be used in cyber resiliency analysis, and cyber resiliency
 1182 analysis enables cyber risks to be considered more fully in life cycle and RMF tasks.

1183

TABLE 5: TAILORABLE PROCESS FOR CYBER RESILIENCY ANALYSIS

| ANALYSIS STEP | MOTIVATING QUESTION | TASKS |
|--|--|---|
| Understand the context | How do stakeholder concerns and priorities translate into cyber resiliency constructs and priorities? | <ul style="list-style-type: none"> Identify the programmatic context. Identify the architectural context. Identify the operational context. Identify the threat context. Interpret and prioritize cyber resiliency constructs. |
| Establish the initial cyber resiliency baseline | How well is the system doing (i.e., how well does it meet stakeholder needs and address stakeholder concerns) with respect to the aspects of cyber resiliency that matter to stakeholders? | <ul style="list-style-type: none"> Identify existing capabilities. Identify gaps and issues. Define evaluation criteria and make an initial assessment. |
| Analyze the system | How do cyber risks affect mission, business, or operational risks? | <ul style="list-style-type: none"> Identify critical resources, sources of fragility, and attack surfaces. Represent the adversary perspective. Identify and prioritize opportunities for improvement. |

³⁸ See [Section D.3](#).

| ANALYSIS STEP | MOTIVATING QUESTION | TASKS |
|---|--|---|
| Define and analyze specific alternatives | How can mission or operational resilience be improved by improving cyber resiliency? | <ul style="list-style-type: none"> • Define potential technical and procedural solutions. • Define potential solutions for supporting systems and processes. • Analyze potential solutions with respect to criteria. |
| Develop recommendations | What is the recommended plan of action? | <ul style="list-style-type: none"> • Identify and analyze alternatives. • Assess alternatives. • Recommend a plan of action. |

1184

1185 **3.2.1 Understand the Context**

1186 The problem of providing sufficient cyber resiliency properties and behaviors is inherently
 1187 situated in a programmatic, operational, architectural, and threat context. This step is intended
 1188 to ensure that the context is sufficiently understood and that cyber resiliency constructs can be
 1189 interpreted in that context, the relative priorities of cyber resiliency objectives can be assessed,
 1190 and the applicability of cyber resiliency design principles, techniques, and approaches can be
 1191 determined. The activities in this step can and should be integrated into activities under the
 1192 Technical Management Processes in [[SP 800-160 v1](#)] and the Prepare and Categorize steps of
 1193 the RMF [[SP 800-37](#)].

1194 **3.2.1.1 Identify the Programmatic Context**

1195 The programmatic context identifies how the system-of-interest is being acquired, developed,
 1196 modified, or repurposed, including the life cycle stage, life cycle model, or system development
 1197 approach (e.g., spiral, waterfall, agile, DevOps). Identification of the life cycle stage, life cycle
 1198 model, and system development approach enables maturity as a consideration in defining cyber
 1199 resiliency solutions. The programmatic context also identifies the stakeholders for the system-
 1200 of-interest, the roles and responsibilities related to the system-of-interest, and the entities
 1201 (organizations, organizational units, or individuals) in those roles.

1202 In particular, the programmatic context identifies the entities responsible for directing,
 1203 executing, and determining the acceptability of the results of engineering efforts related to the
 1204 system (e.g., program office, systems engineer, systems integrator, authorizing official, and
 1205 mission or business function owner). Each of these key stakeholders has a risk management
 1206 strategy focused on different potential risks (e.g., cost, schedule, and technical or performance
 1207 risks for a program office or systems engineer; security risks for an authorizing official; mission
 1208 or business risks for a mission or business function owner). When these entities are part of the
 1209 same organization, the risk management strategies for their respective areas of responsibility
 1210 instantiate or are aligned with the organization's cyber risk management strategy.³⁹

1211 Technical or performance risks can include risks that quality properties (e.g., security, safety,
 1212 system resilience, cyber resiliency) are insufficiently provided, as evidenced by the absence or
 1213 poor execution of behaviors that should demonstrate those properties. The programmatic risk
 1214 management strategy can reflect the relative priorities that other stakeholders—in particular,

³⁹ See [Section 3.1.2](#).

1215 the mission or business process owner and the authorizing official—assign to different quality
1216 properties. In addition, the programmatic risk management strategy can include constraints on
1217 less mature technologies, less commonly used products, or less commonly applied operational
1218 practices as part of managing technical or performance risks.⁴⁰

1219 In addition, other stakeholders may have their own risk management strategies or may be
1220 represented by an official within these entities (e.g., a system security officer to represent the
1221 security concerns of program managers whose proprietary information is handled by the
1222 system-of-interest) with a corresponding risk management strategy. An appreciation of the
1223 different risk management strategies (i.e., how the various stakeholders frame risk, including
1224 what threats and potential harms or adverse consequences are of concern to them, what their
1225 risk tolerances are, and what risk trade-offs they are willing to make) will enable the threat
1226 model to be defined and cyber resiliency constructs to be interpreted and prioritized in
1227 subsequent steps.

1228 The programmatic context is not static. Technical, schedule, or security risks can include risks
1229 related to other programs or initiatives within the organization, its partners, or its suppliers. The
1230 design of the system-of-interest could assume successful completion of milestones by other
1231 programs or initiatives prior to a step in its development, contributing to technical or schedule
1232 risks. Schedule slips or failures to meet specific requirements by other programs or initiatives
1233 could also increase the attack surface of the system-of-interest or make it more fragile. Thus,
1234 understanding which other programs or initiatives could affect the system-of-interest is part of
1235 identifying the programmatic context.⁴¹

1236 Identification of the programmatic context highlights the aspects of the programmatic risk
1237 management strategy that constrain possible solutions. One aspect is the relative priority of
1238 such quality attributes as safety, security, reliability, maintainability, system resilience, and
1239 cyber resiliency. Another is the relative preference for operational changes versus technical
1240 changes. Depending on the life cycle stage and the programmatic risk management strategy,
1241 changes to operational processes and procedures may be preferred to technical changes to the
1242 system.

1243 **3.2.1.2 Identify the Architectural Context**

1244 The architectural context identifies the type of system; its architecture or architectural patterns,
1245 if already defined; and its interfaces with or dependencies on other systems with consideration
1246 of whether it is (or is intended to be) part of a larger system-of-systems or a participant in a
1247 larger ecosystem. Key technologies, technical standards, or products included (or expected to be
1248 included) in the system are identified. Depending on the life cycle stage, identification of the
1249 architectural context can also include system locations, sub-systems or components, or layers in
1250 the architecture where cyber resiliency solutions could be applied. If this information is not yet
1251 available, it will be developed in a subsequent step.⁴²

⁴⁰ See [Section 3.1.8](#).

⁴¹ See [Section 2.3](#).

⁴² See [Section 3.2.3.3](#).

1252 Identification of the type of system begins with identification of its general type (e.g., CPS,⁴³ application, enterprise service, common infrastructure as part of enterprise IT [EIT] or a large-
1253 scale processing environment [LSPE], EIT as a whole, or LSPE as a whole). The type of system
1254 determines which cyber resiliency techniques and approaches are most relevant.⁴⁴ Each type of
1255 system has an associated set of architectural patterns. For example, a CPS device typically
1256 includes a sensor, a controller (which is present in cyberspace), an actuator, and a physical layer;
1257 EIT typically includes enterprise services (e.g., identity and access management, mirroring and
1258 backup, email), common infrastructures (e.g., an internal communications network, a storage
1259 area network, a virtualization or cloud infrastructure), a demilitarized zone (DMZ) for interfacing
1260 with the Internet, and a collection of enterprise applications.
1261

1262 Identification of other systems with which the system-of-interest interfaces or on which it
1263 depends includes consideration of federation, networking, and scope. Federation typically
1264 restricts the set of solutions that can be applied and the metrics that can be defined and used
1265 since different system owners may be unwilling or unable to use the same technologies or share
1266 certain types or forms of information. Some systems are designed to operate without a network
1267 connection, at least transiently and often normally. The cyber resiliency solutions and means of
1268 assessing system cyber resiliency or solution effectiveness will be limited by whether the system
1269 is operating in detached mode. Depending on the programmatic context, the scope of “other
1270 systems” can include those constituting the system’s development, test, or maintenance
1271 environment.

1272 **3.2.1.3 Identify the Operational Context**

1273 The operational context identifies how the system-of-interest is used or will be used (i.e., its
1274 usage context, which is closely related to the architectural context), how it will be administered
1275 and maintained (i.e., its support context, which is closely related to the programmatic and
1276 architectural contexts), how it interacts with or depends on other systems (i.e., its dependency
1277 context), and how usage and dependencies change depending on the time or circumstances
1278 (i.e., its temporal context).

1279 The *usage context* identifies the primary mission or business functions that the system supports,
1280 any secondary or supporting missions or business functions, and the criticality and reliability
1281 with which the missions or business functions are to be achieved. Thus, the usage context can:

- 1282 • Describe the system in terms of its intended uses, which include not only its primary mission
1283 or business function but also secondary or likely additional uses. The description includes
1284 identification of external interfaces—to networks, other supporting infrastructures and
1285 services, and end users—in a functional sense, keeping in mind that these interfaces can
1286 vary.
- 1287 • Describe the system’s criticality to its missions, stakeholders, end users, or the general
1288 public. Criticality is “an attribute assigned to an asset that reflects its relative importance or
1289 necessity in achieving or contributing to the achievement of stated goals” [[SP 800-160 v1](#)]
1290 and relates strongly to the potential impacts of system malfunction, degraded or denied

⁴³ Multiple levels of aggregation have been defined for CPS: a device, a system, or a system-of-systems [[CPSPWG16](#)]. For example, a smart meter is an example of a CPS device; a vehicle is an example of a CPS; and the Smart Grid is an example of a system-of-systems CPS.

⁴⁴ See [Section 3.1.3](#).

- 1291 performance, or not performing to the missions it supports, human life or safety, national
1292 security, or economic security (e.g., as in the context of critical infrastructure [[NIST CSF](#)]).
- 1293 • Identify whether the system is or contains high-value assets (HVAs) (e.g., as defined in [[OMB](#)
1294 [M-19-03](#)], repositories of large volumes of PII or financial assets) or plays a central role
1295 (even if non-critical) in a critical infrastructure sector (e.g., financial services, Defense
1296 Industrial Base [DIB]) since these characteristics could attract specific types of adversaries.
- 1297 • If possible, identify measures of effectiveness (MOEs) and measures of performance (MOPs)
1298 for organizational missions or business functions. Cyber resiliency effectiveness metrics,
1299 which can be defined and used later in the analysis process,⁴⁵ can sometimes repurpose
1300 mission MOEs, MOPs, or data collected to evaluate MOEs and MOPs and can often be
1301 related to MOEs and MOPs, particularly for cyber resiliency metrics related to Withstand or
1302 Recover.
- 1303 The usage context also provides a general characterization of the system user population,
1304 including its size, scope, and assumed user awareness of and ability to respond to cyber threats.
1305 The usage context also indicates whether cyber defenders are actively involved in monitoring
1306 the system and responding to indications and warnings (I&W) of adverse conditions or
1307 behaviors.
- 1308 The *support context* similarly provides a general characterization of the administrative and
1309 maintenance population, describes how system maintenance or updates are performed, and
1310 describes operational restrictions on maintenance activities or updates. For example, updates to
1311 embedded control units (ECUs) in a vehicle should be disallowed when driving. These aspects of
1312 the operational context determine the extent to which procedural solutions can be applied to
1313 the system-of-interest.
- 1314 The *dependency context* identifies adjacent systems (i.e., systems with which the system-of-
1315 interest is connected); describes the types of information received from, supplied to, or
1316 exchanged with those systems; and identifies the criticality of the information connection to the
1317 system-of-interest and to the mission or business functions it supports. The dependency context
1318 also identifies infrastructures on which the system-of-interest depends (e.g., networks, power
1319 suppliers, and environmental control systems). These aspects of the operational context are
1320 used to bound the scope of the analysis (e.g., whether and for which adjacent or infrastructure
1321 systems changes are in scope, whether characteristics and behavior of these systems can be
1322 investigated or must be assumed). If the system-of-interest is part of a larger system-of-systems
1323 or is a participant in a larger ecosystem, the dependency context also identifies the implications
1324 of aggregation or federation for governance, system administration, and information sharing
1325 with other organizations or systems.
- 1326 The *temporal context* identifies whether and how the usage and dependency contexts can
1327 change, depending on whether the system is operating under normal, stressed, or maintenance
1328 conditions; whether the system is being used for one of its secondary purposes; and how the
1329 system's usage and dependencies change over the course of executing mission or business
1330 functions.

⁴⁵ See [Section 3.2.2.3](#) and [Section 3.2.4.3](#).

1331 Information about the support and dependency contexts can be used at this point in the
1332 analysis to characterize and subsequently identify the system's attack surfaces.⁴⁶ The
1333 operational context can be communicated by defining a motivating operational scenario or a
1334 small set of operational scenarios.

1335 **3.2.1.4 Identify the Threat Context**

1336 The threat context identifies threat sources, threat events, and threat scenarios of concern for
1337 the system-of-interest. In particular, the threat context helps to identify the characteristics and
1338 behaviors of adversaries whose attacks would necessarily undermine the system's ability to
1339 execute or support its missions, as well as the characteristics of relevant non-adversarial threats.
1340 Adversaries can include insiders as well as individuals or groups located outside of the system's
1341 physical and logical security perimeter. Adversary goals are identified and translated into cyber
1342 and mission effects. Adversary behaviors (i.e., threat events, attack scenarios, or TTPs) are also
1343 identified.

1344 The threat context can:

1345 • Identify the types of threats considered in programmatic or organizational risk framing. In
1346 addition to adversarial threats, these can include non-adversarial threats of human error,
1347 faults and failures, and natural disasters. A cyber resiliency analysis can identify scenarios in
1348 which adversaries can take advantage of the consequences of non-adversarial threat events.

1349 • Identify the adversary's characteristics, to construct an adversary profile. Characteristics can
1350 include the adversary's ultimate goals and intended cyber effects, the specific time frame
1351 over which the adversary operates, the adversary's persistence (or, alternately, how easily
1352 the adversary can be deterred, discouraged, or redirected to a different target), the
1353 adversary's concern for stealth, and the adversary's targeting, which relates to the scope or
1354 scale of the effects that the adversary intends to achieve. Note that multiple adversaries can
1355 be profiled.

1356 • Identify the types of threat events or adversarial behaviors of concern. Behaviors are
1357 described in terms of adversary TTPs and can be categorized using the categories of the
1358 Adversarial Tactics, Techniques, and Common Knowledge (ATT&CK) framework [[Strom17](#)] or
1359 .govCAR [[DHSCDM](#)].

1360 • Identify the representative attack scenarios of concern, describing each scenario with a
1361 phrase or a sentence. A set of general attack scenarios (e.g., as identified in [[Bodeau18a](#)]
1362 [[Bodeau16](#)]) can serve as a starting point. The attack scenarios of concern in the cyber
1363 resiliency use case should be clearly related to the system's mission. Note that a cyber
1364 resiliency analysis can focus on a single attack scenario or consider a set of scenarios.

1365 A threat model can also include representative threat scenarios related to non-adversarial
1366 threat sources. For these, the scope or scale of effects, duration or time frame, and types of
1367 assets affected are identified. If possible, provide a reference to a publicly available description
1368 of a similar scenario to serve as an anchoring example.

1369 Depending on its scope and purpose, a cyber resiliency analysis can focus on a single threat
1370 scenario. For example, a cyber resiliency analysis can be motivated by a publicized incident with

⁴⁶ See [Section 3.2.3.1](#).

1371 the purpose of the analysis being to determine the extent to which a particular system, mission
1372 or business function, or organization could be affected by a similar incident.

1373 **3.2.1.5 Interpret and Prioritize Cyber Resiliency Constructs**

1374 To ensure that cyber resiliency concepts and constructs are meaningful in the identified
1375 contexts, one or more of the following sub-tasks can be performed:

- 1376 • Restate and prioritize cyber resiliency objectives⁴⁷ and sub-objectives.⁴⁸ Identify, restate,
1377 and prioritize capabilities or activities that are needed to achieve relevant sub-objectives in
1378 light of the identified threat context. These constructs are restated in terms that are
1379 meaningful in the architectural and operational contexts and prioritized based on
1380 programmatic considerations and stakeholder concerns. Note that responsibility for some
1381 capabilities or activities may be allocated to system elements outside of the scope of the
1382 engineering or risk management decisions that the cyber resiliency analysis is intended to
1383 support.
- 1384 • Determine the potential applicability of cyber resiliency design principles. This involves
1385 considering organizational and programmatic risk management strategies to determine
1386 which strategic design principles may apply. It also involves considering the architecture,
1387 operational context, and threat environment to identify the relevance of structural design
1388 principles to this situation. Relevant structural design principles are restated in situation-
1389 specific terms (e.g., in terms of the technologies that are part of the system).
- 1390 • Determine the potential applicability of cyber resiliency techniques and (depending on the
1391 level of detail with which the architectural context is defined) implementation approaches.
1392 This involves considering the architecture, operational context, and threat context. The
1393 relevance of the techniques and approaches to this situation is described and assessed.
1394 Relevant techniques and approaches can be restated and described in terms of architectural
1395 elements (e.g., allocating an implementation approach to a specific system element or
1396 identifying an architectural layer at which a technique can be applied). However, detailed
1397 descriptions are generally deferred to a later stage in a cyber resiliency analysis.⁴⁹

1398 The determination that some cyber resiliency constructs are not applicable, based on the
1399 considerations discussed in [Section 3.1](#), narrows the focus of subsequent steps in the cyber
1400 resiliency analysis, which saves work and increases the usefulness of the results.

1401 **3.2.2 Develop the Cyber Resiliency Baseline**

1402 In order to determine whether cyber resiliency improvement is needed, the baseline for the
1403 system (as it is understood at the stage in the life cycle when the cyber resiliency analysis is
1404 performed) must be established.

1405 **3.2.2.1 Establish the Initial Cyber Resiliency Baseline**

1406 As discussed in [Section 3.1.5.1](#), a system reflects architectural and design decisions and
1407 investments in specific technologies and products motivated by other specialty engineering

⁴⁷ See [Section 3.1.1](#).

⁴⁸ See [Appendix D, Table D-1](#).

⁴⁹ See [Section 3.2.3.3](#).

1408 disciplines. Capabilities are identified from such functional areas as COOP and contingency
1409 planning; security, cybersecurity, and cyber defense; performance management; reliability,
1410 maintainability, and availability (RMA); safety; and survivability. Identification of capabilities can
1411 involve decomposition of the system-of-interest into constituent sub-systems, functional areas,
1412 and/or architectural locations.⁵⁰

1413 Capabilities can be characterized in terms of the cyber resiliency techniques and approaches
1414 they can implement and/or the cyber resiliency design principles they can be used to apply.
1415 Capabilities can also be characterized in terms of how easily their configuration or operational
1416 use can be adapted to address specific cyber resiliency concerns, how dynamically they can be
1417 reconfigured or repurposed, and how compatible they are with other cyber resiliency
1418 techniques and approaches (e.g., deception, unpredictability).

1419 **3.2.2.2 Identify Gaps and Issues**

1420 Depending on the life cycle stage, issues may already be tracked, or it may be possible to
1421 identify gaps in required capabilities and issues with the system's design, implementation, or
1422 use. Such information can be found in after-action reports from exercises, penetration test
1423 reports, incident reports, and reporting related to ongoing assessments and ongoing risk
1424 response actions (RMF tasks M-2 and M-3) [[SP 800-37](#)]. Security gaps may also have been
1425 identified from a coverage analysis with respect to a taxonomy of attack events or TTPs
1426 [[DHSCDM](#)].

1427 Because senior leadership is often aware of issues and gaps, recommended cyber resiliency
1428 solutions will need to be characterized in terms of how and how well the solutions address the
1429 issues and gaps, as well as in terms of other benefits that the recommended solutions provide
1430 (e.g., improved stability, improved performance).

1431 **3.2.2.3 Define Evaluation Criteria and Make Initial Assessment**

1432 One or more evaluation criteria are established and used to make an initial assessment. Cyber
1433 resiliency can be evaluated in multiple ways, including:

- 1434 • How well the system achieves (or, assuming it meets its requirements, will achieve) cyber
1435 resiliency objectives and sub-objectives (considering the priority weighting established
1436 earlier),⁵¹ can provide capabilities, or perform activities supporting achievement of cyber
1437 resiliency objectives. An initial assessment can be expressed as high-level qualitative
1438 assessments (e.g., on a scale from Very Low to Very High) for the cyber resiliency objectives
1439 and subsequently refined based on analysis of the system. An initial assessment can also
1440 take the form of a cyber resiliency coverage map, indicating whether and how well the
1441 relevant cyber resiliency constructs that were determined to be relevant have been
1442 applied.⁵² Alternately (if the information is available) or subsequently (based on the analysis
1443 described in [Section 3.2.3.1](#) and [Section 3.2.3.3](#)),⁵³ this assessment can be expressed as a
1444 cyber resiliency score.

⁵⁰ See [Section 3.1.6](#).

⁵¹ See [Section 3.2.1.5](#).

⁵² See [Section 3.2.1.5](#).

⁵³ See [Section 3.2.4.3](#).

- 1445 • How well the system's capabilities cover (i.e., have at least one effect on) adversary
1446 activities as identified by the threat context.⁵⁴ This can be expressed as a threat heat map
1447 [[DHSCDM](#)] or a simple threat coverage score. For an initial assessment, coverage can be in
1448 terms of attack stages.⁵⁵ Alternately or subsequently, a more nuanced threat coverage score
1449 based on the organization's risk management strategy can be computed using the relative
1450 priorities of the general types of effects (e.g., increase adversary cost, decrease adversary
1451 benefits, increase adversary risk) and of the specific effects (e.g., redirect, preclude, impede,
1452 detect, limit, expose) if the risk management strategy establishes such priorities.
- 1453 • The level of cyber risk in terms of risk to missions, business functions, or other forms of risk
1454 (e.g., security, safety, reputation). An assessment of this form is possible if the organization
1455 has established a risk model, or at least a consequence model, for such forms of risk. An
1456 initial assessment will typically rely on an existing security risk assessment [[SP 800-30](#)].
- 1457 • The level of operational resilience (i.e., mission or business function resilience) in terms of
1458 functional performance measures under stress. An assessment of this form is possible if the
1459 organization has established such performance measures. An initial assessment will typically
1460 rely on an existing performance assessment, which describes operational resilience in the
1461 face of prior incidents and will be subject to uncertainty since prior incidents may be poor
1462 predictors of future ones.

1463 Additional evaluation criteria can consider how well the system meets its security requirements
1464 or achieves its security objectives and how well the system satisfies its mission or business
1465 function requirements. While such evaluations are independent of cyber resiliency analysis, they
1466 can form part of the baseline against which potential solutions can be evaluated.

1467 Stakeholder concerns and priorities are used to determine which (or which combination) of
1468 these will be used to evaluate alternative solutions. Approaches to assessment (e.g., scoring
1469 systems, qualitative assessment scales, metrics and measures of effectiveness) and candidate
1470 metrics can be identified for use in subsequent steps. In addition, evaluation criteria can involve
1471 assessments of potential costs in terms of financial investment over subsequent life cycle stages
1472 (e.g., acquiring, integrating, operating, and maintaining a cyber resiliency solution), opportunity
1473 costs (e.g., constraints on future engineering decisions or system uses), and increased
1474 programmatic risk (e.g., potential cost risk, schedule impacts, performance impacts).

1475 **3.2.3 Analyze the System**

1476 In this step, the system is analyzed in its operational context from two perspectives. First, a
1477 mission or business function perspective is applied to identify critical resources (i.e., those
1478 resources for which damage or destruction would severely impact operations) and sources of
1479 system fragility. Second, an adversarial perspective is applied to identify high-value primary and
1480 secondary targets of APT actors [[OMB M-19-03](#)] and develop representative attack scenarios.
1481 Based on this analysis and the results of the previous baseline assessment, opportunities for
1482 improvement are identified.

⁵⁴ See [Appendix F](#).

⁵⁵ See [Section F.2](#).

1483 **3.2.3.1 Identify Critical Resources, Sources of Fragility, and Attack Surfaces**

1484 A critical resource can be a resource for which damage (e.g., corruption or reduced availability),
1485 denial of service, or destruction results in the inability to complete a critical task. In addition, if a
1486 resource is used in multiple tasks, it can be highly critical overall even if it is not critical to any of
1487 those functions individually if its damage, denial, or destruction results in a delay for a time-
1488 critical mission or business function. Critical resources can be identified using a variety of
1489 methods specific to contingency planning, resilience engineering, and mission assurance. These
1490 include Criticality Analysis [IR 8179], Mission Impact Analysis (MIA), Business Impact Analysis
1491 (BIA) [[SP 800-34](#)], Crown Jewels Analysis (CJA), and cyber mission impact analysis (CMIA).

1492 For cyber resiliency analysis, the identification of critical resources is based on an understanding
1493 of functional flows or of mission or business function threads. A resource can be highly critical at
1494 one point in a functional flow or a mission thread and of very low criticality at other points. A
1495 functional flow analysis or a mission thread analysis can reveal such time dependencies.

1496 Systems can also be analyzed to identify sources of fragility or brittleness. While identification of
1497 single points of failure is a result of the analysis methods mentioned above, network analysis or
1498 graph analysis (i.e., analysis of which system elements are connected, how and how tightly the
1499 system elements are connected, and whether some sets of system elements are more central)
1500 can determine whether the system is fragile (i.e., whether it will break if a stress beyond a well-
1501 defined set is applied). Similarly, graphical analysis of the distribution of different types of
1502 components can help determine how easily a given stress (e.g., exploitation of a zero-day
1503 vulnerability) could propagate.

1504 Finally, the attack surfaces to which cyber resiliency solutions can be applied can be identified.
1505 Information about the programmatic, architectural, and operational context determines which
1506 attack surfaces are within the scope of potential cyber resiliency solutions. For example, if the
1507 programmatic context determines support systems to be in scope, those systems are an attack
1508 surface in addition to the interfaces and procedures by which updates are made to the system-
1509 of-interest; if the system-of-interest is an enterprise service (architectural context), its interfaces
1510 to other services on which it depends as well as to applications which use it are also attack
1511 surfaces; if the system has users (operational context), the user community is an attack
1512 surface.⁵⁶

1513 **3.2.3.2 Represent the Adversary Perspective**

1514 As described in [Section 3.2.1](#), cyber resiliency analysis assumes an architectural, operational,
1515 and threat context for the system being analyzed. These contextual assumptions provide the
1516 starting point for a more detailed analysis of how an adversary could adversely affect the system
1517 and thereby cause harm to the mission or business functions it supports, the organization,
1518 individuals for whom the system handles PII or whose safety depends on the system, or the
1519 environment. The attack scenarios of concern that were identified as part of the threat context
1520 serve as a starting point.⁵⁷ Depending on the scope of the analysis,⁵⁸ these attack scenarios can

⁵⁶ See [Section D.5.1.3](#).

⁵⁷ See [Section 3.2.1.4](#).

⁵⁸ As noted in [Section 3.2.1.4](#), a cyber resiliency analysis can be focused on a single attack scenario.

1521 be complemented by scenarios driven by adversary goals, scenarios targeting critical assets or
1522 high-value assets,⁵⁹ or scenarios that take advantage of sources of fragility.

1523 The adversary perspective (i.e., what harm can be done, how easily, and at what cost to the
1524 attacker) can be represented in different ways, depending on the stage of the system life cycle
1525 and the corresponding level and amount of information about the system architecture, design,
1526 implementation, and operations. At a minimum, an attack scenario can identify stages in the
1527 attack (e.g., administer, engage, persist, cause effect, and maintain ongoing presence), the
1528 adversary objectives or categories of TTPs at each stage (e.g., reconnaissance, exploitation,
1529 lateral movement, denial), and the system elements compromised in each stage. Depending on
1530 the system life cycle stage, it may be possible to identify individual TTPs (e.g., pass the hash) or
1531 examples of specific malware.⁶⁰

1532 Attack scenarios can be represented as part of a model-based engineering effort; using attack
1533 tree or attack graph analysis; in terms of fault tree analysis or failure modes, effects, and
1534 criticality analysis (FMECA); or based on the identification of loss scenarios from System-
1535 Theoretic Process Analysis (STPA). Common elements across the attack scenarios (e.g., recurring
1536 adversary TTPs) can be starting points for identifying potential alternative solutions.

1537 Depending on the scope of the cyber resiliency analysis, attack scenarios can be developed that
1538 target supporting systems. Such attack scenarios may be the result of a supply chain risk analysis
1539 or a cyber resiliency or cybersecurity analysis of systems or organizations responsible for
1540 development, integration, testing, or maintenance.

1541 **3.2.3.3 Identify and Prioritize Opportunities for Improvement**

1542 The identification of potential areas of improvement typically relies on the interpretation and
1543 prioritization of cyber resiliency constructs performed earlier.⁶¹ Potential cyber resiliency
1544 techniques or implementation approaches can be identified in system-specific terms, mapped to
1545 system elements or architectural layers, and stated as desired improvements to system
1546 elements or to the system as a whole. Desired improvements are prioritized based on how and
1547 how well they are expected to reduce risks as identified by stakeholders.⁶²

1548 In more detail, this task in the analysis process can include the following sub-tasks:

- 1549 • Identify potentially applicable techniques or approaches. If the set of potentially applicable
1550 techniques and approaches has already been identified,⁶³ it can be narrowed by identifying
1551 the set of techniques and approaches related to prioritized objectives using [Appendix D](#),
1552 [Table D-13](#) or to potentially applicable structural design principles using [Table D-15](#). (If only
1553 the applicable strategic design principles were identified, [Table D-14](#) can be used to identify
1554 relevant objectives and [Table D-10](#) can be used to identify relevant structural design
1555 principles.) Otherwise, the set of techniques and approaches related to prioritized

⁵⁹ See [OMB M-19-03](#).

⁶⁰ However, specific malware should be treated as a motivating example only. Cyber resiliency engineering assumes that unforeseen malware can be used and seeks to mitigate types of adversary actions.

⁶¹ See [Section 3.2.1.5](#).

⁶² See [Section 3.2.1.1](#).

⁶³ See [Section 3.2.1.5](#).

- objectives or structural design principles can be refined by taking the architectural and programmatic context into consideration. The potentially applicable techniques or approaches are described in system-specific terms.
- Identify locations where cyber resiliency solutions could be applied.⁶⁴ The set of locations (i.e., sub-systems or components, layers in the architecture, or interfaces between sub-systems or between layers) where cyber resiliency solutions could be applied is determined by the system architecture as constrained by context.⁶⁵ For example, the programmatic context may prioritize cyber resiliency solutions that change how existing technologies are used over changes to the system architecture (e.g., replacing specific system elements); the architectural context may restrict locations to specific interfaces (e.g., if the system-of-interest is an enterprise service, solutions may be applied to its interfaces with sub-systems or applications which use it or with supporting services, particularly security services); or the operational context may constrain the extent to which new user procedures can be made part of the system (e.g., depending on the size of, cyber expertise of, or organizational control over the user population).
 - Identify desired improvements to system elements or to the system-of-interest as a whole. Statements of desired improvements described in terms specific to the architectural and operational context can be more meaningful to stakeholders than general statements about improved use of a cyber resiliency technique or a more effective application of a cyber resiliency design principle. Potential improvements can be described in terms of improved protection for critical resources, reduced fragility, or the ability to address threats more effectively.
 - Prioritize desired improvements using the identified evaluation criteria (e.g., improve the ability of a given system element to continue functioning by enabling that element to be dynamically isolated, decrease adversary benefits by reducing the concentration of highly-sensitive information in a single asset, or reduce mission risks by providing extra resources for high-criticality tasks).

3.2.4 Define and Analyze Specific Alternatives

In this step, specific ways to make desired improvements (i.e., architectural changes, ways to implement cyber resiliency techniques in the context of the existing architecture, ways to use existing system capabilities more effectively to improve resilience) are identified and analyzed in terms of potential effectiveness. These specific alternatives form a solution set, which will be used in the final step to construct potential courses of action.

3.2.4.1 Define Potential Technical and Procedural Solutions

Potential applications of cyber resiliency techniques and implementation approaches to the system-of-interest in its environment of operations in order to provide one or more desired improvements are identified.⁶⁶ These applications (i.e., potential solutions to the problem of improving mission or operational resilience by improving cyber resiliency) can be purely technical, purely procedural, or combinations of the two.

⁶⁴ See [Section 3.1.6](#).

⁶⁵ See [Section 3.2.1](#).

⁶⁶ See [Section 3.2.3.3](#).

1595 Potential solutions can incorporate or build on investments from other disciplines.⁶⁷ The set of
1596 technologies and products that are available at some level of maturity⁶⁸ for incorporation into
1597 the system depends on the type of the system.⁶⁹ The degree to which relatively immature
1598 technologies can be considered depends on the programmatic risk management strategy.⁷⁰

1599 The level of detail with which a potential solution is described depends on how specifically the
1600 context was described in the first step.⁷¹ In particular, if the architectural and operational
1601 contexts were described in general terms, potential solutions will necessarily be described at a
1602 high-level. On the other hand, if the cyber resiliency analysis is being performed for an existing
1603 system, a potential solution can be described in terms of specific technologies or products to be
1604 integrated into the system, where in the system those technologies will be used, how they will
1605 interface with other system elements, configuration settings or ranges of settings for products,
1606 and processes or procedures to make effective use of existing or newly acquired technologies.

1607 The description of a potential solution can include identification of the gaps it is expected to
1608 address,⁷² the threats (e.g., attack scenarios, adversary objectives or categories of TTPs, or
1609 adversary actions) it is intended to address,⁷³ or the reduced exposure of critical resources,
1610 sources of fragility, or attack surfaces to threats.⁷⁴ These different elements of a potential
1611 solution's description can be used to evaluate the solution.⁷⁵

1612 **3.2.4.2 Define Potential Solutions for Supporting Systems and Processes**

1613 If programmatic and operational contexts support improvements to supporting systems and
1614 processes, the potential applications of cyber resiliency techniques and approaches to these
1615 systems and processes are also identified. Such applications can include modifications to
1616 contracting to help ensure that controlled unclassified information (CUI) or other sensitive
1617 information is protected [SP 800-171], improvements to supply chain risk management (SCRM)
1618 as determined by SCRM analysis [SP 800-161], and restrictions on or re-architecting of system
1619 development, testing, or maintenance environments to improve the cyber resiliency of those
1620 environments.

1621 **3.2.4.3 Analyze Potential Solutions with Respect to Criteria**

1622 Potential solutions can be analyzed with respect to one or more criteria.⁷⁶ Evaluation can
1623 employ qualitative or semi-quantitative assessments (using subject matter expert [SME]
1624 judgments) or quantitative metrics (evaluated in a model-based environment, laboratory, cyber
1625 range, or test environment; metrics to support analysis of alternatives are typically not

⁶⁷ See [Section 3.1.5](#).

⁶⁸ See [Section 3.1.8](#).

⁶⁹ See [Section 3.1.3](#).

⁷⁰ See [Section 2.3](#) and [Section 3.2.1.1](#).

⁷¹ See [Section 3.2.1](#).

⁷² See [Section 3.2.2.2](#).

⁷³ See [Section 3.2.3.2](#).

⁷⁴ See [Section 3.2.3.1](#).

⁷⁵ See [Section 3.2.4.3](#).

⁷⁶ See [Section 3.2.2.3](#).

1626 evaluated in an operational environment). Potential solutions can be analyzed to determine, for
1627 example:

- 1628 • How much the solution could improve the ability of the system to achieve its (priority-
1629 weighted) cyber resiliency objectives or sub-objectives. This can be expressed as a change in
1630 a cyber resiliency score or as a coverage map for the relevant cyber resiliency constructs.
1631 Alternately or in support of scoring, performance metrics for activities or capabilities related
1632 to cyber resiliency sub-objectives can be evaluated.
- 1633 • How well the system, with the solution applied, addresses adversary activities or attack
1634 scenarios as identified by the threat context. As noted in [Section 3.2.2.3](#), this can take the
1635 form of a threat heat map or a threat coverage score using a taxonomy of adversary
1636 activities (e.g., [\[MITRE18\]](#)). It can also take the form of an adversary return on investment
1637 (ROI) score or a more nuanced threat coverage score.⁷⁷ Alternately or in support of scoring,
1638 performance metrics for specific types of effects on adversary actions can be defined and
1639 evaluated before and after the solution is applied (e.g., length of time it takes an adversary
1640 to move laterally across a system or an enclave).
- 1641 • How much the solution could improve the system's coverage of adversary TTPs using
1642 capabilities defined in [\[NIST CSF\]](#). This can be expressed as a change in a score or using a
1643 threat heat map [\[DHSCDM\]](#).
- 1644 • How much the solution could decrease the level of cyber risk or a specific component of risk
1645 (e.g., level of consequence). As discussed in [Appendix F](#),⁷⁸ effects on adversary activities
1646 have associated effects on risk.
- 1647 • How much the solution could improve the level of operational resilience in terms of
1648 functional performance measures under stress. As discussed in [Section D.5.1](#), some strategic
1649 design principles for cyber resiliency are closely related to design principles for Resilience
1650 Engineering. Thus, a solution that applies one or more of those design principles can be
1651 expected to improve resilience against non-adversarial as well as adversarial threats.
- 1652 • Whether and how much the solution could improve the system's ability to meet its security
1653 requirements. Evaluation with respect to this criterion can involve qualitative assessments
1654 by subject matter experts (SME), an explanatory description, a list of previously unmet
1655 requirements that the solution can help meet, or specific security performance metrics that
1656 can be evaluated before and after the solution is applied.
- 1657 • Whether and how much the solution could improve the system's ability to meet its mission
1658 or business function performance requirements. Similar to a security requirements criterion,
1659 evaluation with respect to this criterion can involve an explanatory description, qualitative
1660 assessments by SMEs, a list of previously unmet requirements that the solution can help
1661 meet, or specific functional performance metrics that can be evaluated before and after the
1662 solution is applied.

1663 In addition, the potential costs of a solution can be identified or assessed. The product of this
1664 step is a list of alternative solutions, with each alternative characterized (e.g., using a coverage
1665 map or a description) or assessed with respect to the identified criteria.

⁷⁷ See [Appendix F](#).

⁷⁸ See [Table F-1](#).

1666 **3.2.5 Develop Recommendations**

1667 Unless the scope of the cyber resiliency analysis is narrow, the number and variety of potential
1668 solutions may be large. Sets of potential solutions that could be implemented at the same time
1669 can be constructed and analyzed to ensure compatibility, identify possible synergies, and
1670 determine whether specific solutions should be applied sequentially rather than simultaneously.
1671 In addition, programmatic and operational risks associated with alternative solutions can be
1672 identified. The result of this step is a recommended plan of action.

1673 **3.2.5.1 Identify and Analyze Alternatives**

1674 One or more alternatives (i.e., sets of potential solutions that could be implemented at the same
1675 time or sequentially such as in successive spirals) can be identified using either total cost or a
1676 requirement for a consistent level of maturity⁷⁹ (e.g., requiring all technical solutions in the set
1677 to be available as commercial products by a specific milestone) to bound each set. Where
1678 possible, a set of potential solutions should be defined to take advantage of synergies (as
1679 discussed in [Section 3.1.4](#) and identified in [Appendix D, Table D-3](#)). At a minimum, each set
1680 should be analyzed to ensure that there are no internal conflicts. If the solutions in a set are to
1681 be implemented sequentially, functional dependencies among those solutions should be
1682 identified. In addition, functional dependencies on other system elements (particularly those
1683 involving investments due to other disciplines)⁸⁰ should be identified since changes in system
1684 elements can be made for a variety of reasons. Finally, functional dependencies on other
1685 organizational efforts (e.g., programs, initiatives) should be identified to ensure that changes to
1686 the attack surfaces of the system-of-interest, the organization's infrastructure and supporting
1687 services, and other systems or assets are understood and the associated risks managed.⁸¹

1688 **3.2.5.2 Assess Alternatives**

1689 Each alternative can be assessed or characterized in terms of the evaluation criteria.⁸² To
1690 support assessments, the adversarial analysis⁸³ can be revisited for each alternative. Due to
1691 synergies or other interactions between cyber resiliency techniques, changes in scores, heat
1692 maps, or coverage maps must be determined by analysis rather than by simply combining
1693 previously determined values. In addition, each alternative should be analyzed to determine
1694 whether it makes new attack scenarios (or non-adversarial threat scenarios) possible. If it does,
1695 those scenarios should be analyzed to determine whether changes should be made to the
1696 alternative.

1697 Each alternative can also be described in terms of the issues it resolves, the gaps it fills,⁸⁴ or
1698 whether it provides improved protection for critical resources, reduced fragility, or the ability to
1699 address threats more effectively. Finally, each alternative can be assessed or described in terms
1700 of its effects on programmatic risk (e.g., total costs, changes to schedule risk, changes to
1701 technical or performance risk) or other risks of concern to stakeholders. If an alternative

⁷⁹ See [Section 3.1.8](#).

⁸⁰ See [Section 3.1.5](#).

⁸¹ See [Section 2.3](#).

⁸² See [Section 3.2.4.3](#).

⁸³ See [Section 3.2.3.2](#).

⁸⁴ See [Section 3.2.2.2](#).

1702 diverges from the risk management strategies of one or more stakeholders, this divergence
1703 should be noted so that a compensating risk management approach can be made part of the
1704 recommendation if the alternative is in fact recommended.

1705 **3.2.5.3 Recommend a Plan of Action**

1706 A recommended plan of action resulting from a cyber resiliency analysis can take the form of a
1707 set of selected alternatives to be implemented in successive phases. For each phase, the costs,
1708 benefits, and risk management approaches can be identified, accompanied by identification of
1709 circumstances which could indicate the need to revisit the recommendations. However, as
1710 noted in [Section 3.1](#), a cyber resiliency analysis can be narrowly focused. If this is the case, the
1711 recommendations resulting from the analysis will take a form directed by the focus of the
1712 analysis.

CYBER RESILIENCY ENGINEERING
A COMPLEMENT TO OTHER SPECIALTY ENGINEERING DISCIPLINES

As presented in this publication, cyber resiliency engineering is a specialty systems engineering discipline, based on the recognition that (1) mission and business functions depend on systems which include or depend on cyber resources, (2) advanced persistent threat (APT) actors can establish and maintain a covert presence in systems, particularly by compromising cyber resources, and (3) essential organizational missions and business functions must be assured despite the activities of APT actors. The cyber resiliency engineering framework presented in [Section 2.1](#) and the tailororable process for cyber resiliency analysis presented in [Section 3.2](#) are motivated by that recognition. As discussed in those sections and in [Section C.3](#), cyber resiliency engineering draws from, is aligned with, and can support other specialty systems engineering disciplines.

The cyber resiliency goals, objectives, techniques, and design principles, as well as many of the implementation approaches, are defined in technology-neutral terms. This is deliberate, to facilitate alignment with frameworks for other specialty systems engineering disciplines. The representative examples of these constructs are specific to systems which include cyber resources. The selection of the objectives, techniques, design principles, and approaches for inclusion in the cyber resiliency engineering framework is motivated by practical experience with engineering systems with requirements for mission assurance in the face of APT activities, by landscape surveys of existing and emerging technologies and practices for meeting those requirements, and by surveys of various research strategies. The expectation is that the set of representative examples will continue to grow and change, possibly leading to changes in the set of implementation approaches, as technologies and practices for integrating cyber resources into systems continue to evolve.

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1718 APPENDIX A

1719 GLOSSARY

1720 COMMON TERMS AND DEFINITIONS

1721 Appendix A provides definitions for terminology used in NIST SP 800-160, Volume 2.
1722 Sources for terms used in this publication are cited as applicable. Where no citation is
1723 noted, the source of the definition is SP 800-160, Volume 2.

adaptability

The property of an architecture, design, and implementation which can accommodate changes to the threat model, mission or business functions, systems, and technologies without major programmatic impacts.

advanced cyber threat

See *advanced persistent threat*.
Note 1: The phrase “advanced cyber threat” implies either that an adversary executes a cyber attack or that an adversary subverts the supply chain in order to compromise cyber resources.

advanced persistent threat
[\[SP 800-39\]](#)

An adversary that possesses sophisticated levels of expertise and significant resources which allow it to create opportunities to achieve its objectives by using multiple attack vectors including, for example, cyber, physical, and deception. These objectives typically include establishing and extending footholds within the IT infrastructure of the targeted organizations for purposes of exfiltrating information, undermining or impeding critical aspects of a mission, program, or organization, or positioning itself to carry out these objectives in the future. The advanced persistent threat pursues its objectives repeatedly over an extended period; adapts to defenders’ efforts to resist it; and is determined to maintain the level of interaction needed to execute its objectives.

Note 1: While some sources define APT (or advanced cyber threat) as an adversary at Tier V or Tier VI in the threat model in [DSB13]—in particular, to be a state actor—the definition used here includes criminal actors.

Note 2: For brevity, “the APT” refers to any adversary with the characteristics described above or to the set of all such adversaries; “an APT actor” refers to a representative member of that set.

Note 3: The APT may establish its foothold by subverting the supply chain in order to compromise cyber resources. Thus, the APT may be able to achieve its objectives without executing a cyber attack against the organization’s systems (e.g., by inserting a logic bomb or time).

Note 4: The term “APT” does not include the insider threat. However, if an APT actor establishes and extends its foothold by masquerading as a legitimate system user and taking advantage of that user’s authorized access privileges, it may be indistinguishable from an insider threat.

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| adversity | Adverse conditions, stresses, attacks, or compromises. <i>Note 1:</i> The definition of adversity is consistent with the use of the term in [SP 800-160 v1] as disruptions, hazards, and threats. <i>Note 2:</i> Adversity in the context of the definition of cyber resiliency specifically includes but is not limited to cyber attacks. |
| agility | The property of a system or an infrastructure which can be reconfigured, in which resources can be reallocated, and in which components can be reused or repurposed so that cyber defenders can define, select, and tailor cyber courses of action for a broad range of disruptions or malicious cyber activities. |
| approach | See <i>cyber resiliency implementation approach</i> . |
| asset [SP 800-160 v1] | An item of value to stakeholders. An asset may be tangible (e.g., a physical item such as hardware, firmware, computing platform, network device, or other technology component) or intangible (e.g., humans, data, information, software, capability, function, service, trademark, copyright, patent, intellectual property, image, or reputation). The value of an asset is determined by stakeholders in consideration of loss concerns across the entire system life cycle. Such concerns include but are not limited to business or mission concerns. |
| attack surface [SP 800-53, adapted] | The set of points on the boundary of a system, a system element, or an environment where an attacker can try to enter, cause an effect on, or extract data from. <i>Note:</i> An attack surface can be <i>reduced</i> by removing points on the boundary (reducing the <i>extent</i> of the attack surface, e.g., by reducing the amount of code running) or reducing the <i>exposure</i> of some points to an attacker (e.g., by placing inessential functions on a different system element than essential functions, by layering defenses, by reducing the period of exposure); <i>changed</i> by changing the set of points on the boundary (e.g., by moving some points), by changing the exposure of some points to an attacker (e.g., by adding logic to check data or commands), or by changing the properties of some points (e.g., by applying principles of least privilege and least functionality); or <i>disrupted</i> by making changes unpredictably or by reducing its extent or exposure for limited time periods (e.g., by temporarily isolating components). |
| blockchain [IR 8202] [IR 8301] | A distributed digital ledger of cryptographically signed transactions that are grouped into blocks. Each block is cryptographically linked to the previous one (making it tamper evident) after validation and undergoing a consensus decision. As new blocks are added, older blocks become more difficult to modify (creating tamper resistance). New blocks are replicated across copies of the ledger within the network, and any conflicts are resolved automatically using established rules. |
| contested cyber environment | An environment in which APT actors, competing entities, and entities with similar resource needs contend for control or use of cyber resources. |

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| control [ISACA] | The means of managing risk, including policies, procedures, guidelines, practices, or organizational structures, which can be of an administrative, technical, management, or legal nature. <i>Note:</i> See <i>security control</i> . |
| criticality [SP 800-160 v1] | An attribute assigned to an asset that reflects its relative importance or necessity in achieving or contributing to the achievement of stated goals. |
| cyber incident [CNSSI 4009] | Actions taken through the use of an information system or network that result in an actual or potentially adverse effect on an information system, network, and/or the information residing therein. |
| cyber resiliency | The ability to anticipate, withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on systems that use or are enabled by cyber resources. Cyber resiliency is intended to enable mission or business objectives that depend on cyber resources to be achieved in a contested cyber environment. <i>Note:</i> Cyber resiliency can be a property of a system, network, service, system-of-systems, mission or business function, organization, critical infrastructure sector or sub-sector, region, or nation. |
| cyber resiliency concept | A concept related to the problem domain and/or solution set for cyber resiliency. Cyber resiliency concepts are represented in cyber resiliency risk models as well as by cyber resiliency constructs. |
| cyber resiliency construct | Element of the cyber resiliency engineering framework (i.e., a goal, objective, technique, implementation approach, or design principle). Additional constructs (e.g., sub-objectives or methods, capabilities or activities) may be used in some modeling and analytic practices. |
| cyber resiliency control | A control (i.e., a base control or a control enhancement) as defined in [SP 800-53] , which applies one or more cyber resiliency techniques or approaches or which is intended to achieve one or more cyber resiliency objectives. |
| cyber resiliency design principle | A guideline for how to select and apply cyber resiliency analysis methods, techniques, approaches, and solutions when making architectural or design decisions. |
| cyber resiliency engineering practice | A method, process, modeling technique, or analytical technique used to identify and analyze cyber resiliency solutions. |
| cyber resiliency goal | A high-level statement supporting (or focusing on) one aspect (i.e., anticipate, withstand, recover, adapt) in the definition of cyber resiliency. |
| cyber resiliency implementation approach | A subset of the technologies and processes of a cyber resiliency technique defined by how the capabilities are implemented or how the intended consequences are achieved. |

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| cyber resiliency objective | A statement of what must be performed (e.g., what a system must achieve in its operational environment and throughout its life cycle) to meet stakeholder needs for mission assurance and resilient security. |
| cyber resiliency risk model | A risk model which explicitly represents the threats and classes of harm considered by those concerned with cyber resiliency. (This accommodates other stakeholders in addition to systems security engineers.) <i>Note:</i> A cyber resiliency risk model emphasizes (but is not limited to) the APT as a threat source and emphasizes the effects of malicious cyber activities on missions, organizations, and systems that include cyber resources. |
| cyber resiliency solution | A combination of technologies, architectural decisions, systems engineering processes, and operational processes, procedures, or practices that solves a problem in the cyber resiliency domain. A cyber resiliency solution provides enough cyber resiliency to meet stakeholder needs and to reduce risks to mission or business capabilities in the presence of advanced persistent threats. |
| cyber resiliency sub-objective | A statement, subsidiary to a cyber resiliency objective, which emphasizes different aspects of that objective or identifies methods to achieve that objective. |
| cyber resiliency technique | A set or class of technologies and processes intended to achieve one or more objectives by providing capabilities to anticipate, withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on systems that include cyber resources. The definition or statement of a technique describes the capabilities it provides and/or the intended consequences of using the technologies or processes it includes. |
| cyber resource | An information resource which creates, stores, processes, manages, transmits, or disposes of information in electronic form and which can be accessed via a network or using networking methods. <i>Note:</i> A cyber resource is an element of a system that exists in or intermittently includes a presence in cyberspace. |
| cyber risk | The risk of depending on cyber resources (i.e., the risk of depending on a system or system elements which exist in or intermittently have a presence in cyberspace). <i>Note:</i> Cyber risk overlaps with security risk [SP 800-160 v1], information security risk [SP 800-30] [CNSSI 4009], cybersecurity risk [IR 8286], and includes risks due to cyber incidents, cybersecurity events, and cyberspace attacks. |

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| cybersecurity [NIST CSF] [CNSSI 4009] | The process of protecting information by preventing, detecting, and responding to attacks. |
| cybersecurity event [NIST CSF] | Prevention of damage to, protection of, and restoration of computers, electronic communications systems, electronic communications services, wire communication, and electronic communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation. |
| cyberspace [CNSSI 4009] [HSPD23] | A cybersecurity change that may have an impact on organizational operations (including mission, capabilities, or reputation). |
| cyberspace attack [CNSSI 4009] | The interdependent network of information technology infrastructures, and includes the Internet, telecommunications networks, computer systems, and embedded processors and controllers in critical industries. |
| cyber survivability [Pitcher21] | Cyberspace actions that create various direct denial effects (i.e. degradation, disruption, or destruction) and manipulation that leads to denial that is hidden or that manifests in the physical domains. |
| damage | <p>The ability of warfighter systems to prevent, mitigate, recover from and adapt to adverse cyber-events that could impact mission related functions, by applying a risk-managed approach to achieve and maintain an operationally-relevant risk posture, throughout its life cycle.</p> <p>Harm caused to something in such a way as to reduce or destroy its value, usefulness, or normal function.</p> <p><i>Note 1:</i> From the perspective of cyber resiliency, damage can be to the organization (e.g., loss of reputation, increased existential risk), organizational missions or business functions (e.g., decrease in the ability to complete the current mission and to accomplish future missions), security (e.g., decrease in the ability to achieve the security objectives of confidentiality, integrity, and availability or to prevent, detect, and respond to cyber incidents), the system (e.g., decrease in the ability to meet system requirements, unauthorized use of system resources); or specific system elements (e.g., physical destruction; corruption, modification, or fabrication of information).</p> <p><i>Note 2:</i> Damage includes, and in some circumstances can be identified with, asset loss as discussed in [SP 800-160 v1].</p> |
| design principle | A distillation of experience designing, implementing, integrating, and upgrading systems that systems engineers and architects can use to guide design decisions and analysis. A design principle typically takes the form of a terse statement or a phrase identifying a key concept, accompanied by one or more statements that describe how that concept applies to system design (where “system” is construed broadly to include operational processes and procedures, and may also include development and maintenance environments). |

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| enabling system [ISO 15288] | A system that provides support to the life cycle activities associated with the system-of-interest. Enabling systems are not necessarily delivered with the system-of-interest and do not necessarily exist in the operational environment of the system-of-interest. |
| enterprise information technology [IEEE17] | The application of computers and telecommunications equipment to store, retrieve, transmit, and manipulate data, in the context of a business or other enterprise. |
| fault tolerant [SP 800-82] | Of a system, having the built-in capability to provide continued, correct execution of its assigned function in the presence of a hardware and/or software fault. |
| federation [SP 800-95] | A collection of realms (domains) that have established trust among themselves. The level of trust may vary, but typically includes authentication and may include authorization. |
| information resources [OMB A-130] | Information and related resources, such as personnel, equipment, funds, and information technology. |
| information security [OMB A-130] | The protection of information and information systems from unauthorized access, use, disclosure, disruption, modification, or destruction in order to provide confidentiality, integrity, and availability. |
| information system [OMB A-130] | A discrete set of information resources organized for the collection, processing, maintenance, use, sharing, dissemination, or disposition of information. <i>Note:</i> Information systems also include specialized systems such as industrial/process controls systems, telephone switching and private branch exchange (PBX) systems, and environmental control systems. |

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| information technology [OMB A-130] | Any services, equipment, or interconnected system(s) or subsystem(s) of equipment, that are used in the automatic acquisition, storage, analysis, evaluation, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of data or information by the agency. For purposes of this definition, such services or equipment if used by the agency directly or is used by a contractor under a contract with the agency that requires its use; or to a significant extent, its use in the performance of a service or the furnishing of a product. Information technology includes computers, ancillary equipment (including imaging peripherals, input, output, and storage devices necessary for security and surveillance), peripheral equipment designed to be controlled by the central processing unit of a computer, software, firmware and similar procedures, services (including cloud computing and help-desk services or other professional services which support any point of the life cycle of the equipment or service), and related resources. Information technology does not include any equipment that is acquired by a contractor incidental to a contract which does not require its use. |
| mission assurance [DOD16, adapted] | A process to protect or ensure the continued function and resilience of capabilities and assets, including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains, critical to the execution of organizational mission-essential functions in any operating environment or condition. <i>Note:</i> This definition differs from the DoD definition by replacing “DoD” with “organizational.” |
| mission resilience [FMRs20, adapted] | The ability to continuously maintain the capability and capacity to perform essential functions and services, without time delay, regardless of threats or conditions, and with the understanding that adequate warning of a threat may not be available. <i>Note:</i> This definition differs from the source definition by omitting “of the Federal executive branch” after “the ability.” Because essential functions and services are performed using systems, mission resilience can often be identified with operational resilience; usage depends on the intended emphasis. |
| mitigation | A decision, action, or practice intended to reduce the level of risk associated with one or more threat events, threat scenarios, or vulnerabilities. |
| non-adversarial threat | A threat associated with accident or human error, structural failure, or environmental causes. <i>Note:</i> See [SP 800-30] . |

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| operational resilience [CNSSI 4009] | The ability of systems to resist, absorb, and recover from, or adapt to an adverse occurrence during operation that may cause harm, destruction, or loss of the ability to perform mission-related functions. |
| operational technology | Programmable systems or devices that interact with the physical environment (or manage devices that interact with the physical environment). These systems or devices detect or cause a direct change through the monitoring or control of devices, processes, and events. Examples include industrial control systems, building management systems, fire control systems, and physical access control mechanisms. |
| other system [ISO 15288] | A system that the system-of-interest interacts with in the operational environment. These systems may provide services to the system-of-interest (i.e., the system-of-interest is dependent on the other systems) or be the beneficiaries of services provided by the system-of-interest (i.e., other systems are dependent on the system-of-interest). |
| protection [SP 800-160 v1] | In the context of systems security engineering, a control objective that applies across all types of asset types and the corresponding consequences of loss. A system protection capability is a system control objective and a system design problem. The solution to the problem is optimized through a balanced proactive strategy and a reactive strategy that is not limited to <i>prevention</i> . The strategy also encompasses avoiding asset loss and consequences; detecting asset loss and consequences; minimizing (i.e., limiting, containing, restricting) asset loss and consequences; responding to asset loss and consequences; recovering from asset loss and consequences; and forecasting or predicting asset loss and consequences. |
| quality property [SP 800-160 v1] | An emergent property of a system that includes, for example: safety, security, maintainability, resilience, reliability, availability, agility, and survivability. This property is also referred to as a <i>systemic property</i> across many engineering domains. |
| reliability [IEEE90] | The ability of a system or component to function under stated conditions for a specified period of time. |
| resilience [OMB A-130] | The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruption. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. |
| [INCOSE14] | The ability to maintain required capability in the face of adversity. |

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| resilient otherwise [SP 800-160 v1] | Security considerations applied to enable system operation despite disruption while not maintaining a secure mode, state, or transition; or only being able to provide for partial security within a given system mode, state, or transition. See <i>securely resilient</i> . |
| risk [CNSSI 4009] [OMB A-130] | A measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of the adverse impacts that would arise if the circumstance or event occurs; and the likelihood of occurrence. |
| risk analysis [ISO 73] | Process to comprehend the nature of risk and to determine the level of risk. |
| risk assessment [SP 800-39] , adapted [ISO 73] | The process of identifying risks to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation, resulting from the operation of an information system. Part of risk management, incorporates threat and vulnerability analyses, and considers mitigations provided by security controls planned or in place. |
| risk-adaptive access control [SP 800-95] | Overall process of risk identification, risk analysis, and risk evaluation. |
| risk factor [SP 800-30] | Access privileges are granted based on a combination of a user's identity, mission need, and the level of security risk that exists between the system being accessed and a user. RAdAC will use security metrics, such as the strength of the authentication method, the level of assurance of the session connection between the system and a user, and the physical location of a user, to make its risk determination. |
| risk framing [SP 800-39] | A characteristic used in a risk model as an input to determining the level of risk in a risk assessment. |
| risk management strategy [SP 800-39] | Risk framing is the set of assumptions, constraints, risk tolerances, and priorities/trade-offs that shape an organization's approach for managing risk. |
| risk model [SP 800-30] | Strategy that addresses how organizations intend to assess risk, respond to risk, and monitor risk—making explicit and transparent the risk perceptions that organizations routinely use in making both investment and operational decisions. |
| risk response [SP 800-39] | A key component of a risk assessment methodology (in addition to assessment approach and analysis approach) that defines key terms and assessable risk factors. |
| | Accepting, avoiding, mitigating, sharing, or transferring risk to organizational operations (i.e., mission, functions, image, or reputation), organizational assets, individuals, other organizations, or the Nation. |

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| safety [SP 800-82] [MIL-STD-882E] | Freedom from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. |
| securely resilient [SP 800-160 v1] | The ability of a system to preserve a secure state despite disruption, to include the system transitions between normal and degraded modes. Securely resilient is a primary objective of systems security engineering. |
| security [SP 800-160 v1] [ISO 15288] | Freedom from those conditions that can cause loss of assets with unacceptable consequences. |
| [CNSSI 4009] [SP 800-37] | Protection against intentional subversion or forced failure. A composite of four attributes – confidentiality, integrity, availability, and accountability – plus aspects of a fifth, usability, all of which have the related issue of their assurance. |
| security control [SP 800-160 v1] | A condition that results from the establishment and maintenance of protective measures that enable an enterprise to perform its mission or critical functions despite risks posed by threats to its use of information systems. Protective measures may involve a combination of deterrence, avoidance, prevention, detection, recovery, and correction that should form part of the enterprise's risk management approach. |
| security controls [OMB A-130] | <i>Note:</i> See also information security and cybersecurity. A mechanism designed to address needs as specified by a set of security requirements. |
| security criteria | Criteria related to a supplier's ability to conform to security-relevant laws, directives, regulations, policies, or business processes; a supplier's ability to deliver the requested product or service in satisfaction of the stated security requirements and in conformance with secure business practices; the ability of a mechanism, system element, or system to meet its security requirements; whether movement from one life cycle stage or process to another (e.g., to accept a baseline into configuration management, to accept delivery of a product or service) is acceptable in terms of security policy; how a delivered product or service is handled, distributed, and accepted; how to perform security verification and validation; or how to store system elements securely in disposal. |
| security function [SP 800-160 v1] | The capability provided by the system or a system element. The capability may be expressed generally as a concept or specified precisely in requirements. |

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| security relevance [SP 800-160 v1] | The term used to describe those functions or mechanisms that are relied upon, directly or indirectly, to enforce a security policy that governs confidentiality, integrity, and availability protections. |
| security requirement [SP 800-160 v1] | A requirement that specifies the functional, assurance, and strength characteristics for a mechanism, system, or system element. |
| survivability [Richards09] | The ability of a system to minimize the impact of a finite-duration disturbance on value delivery (i.e., stakeholder benefit at cost), achieved through the reduction of the likelihood or magnitude of a disturbance; the satisfaction of a minimally acceptable level of value delivery during and after a disturbance; and/or a timely recovery. |
| system [ISO 15288] [SP 800-160 v1] | Combination of interacting elements organized to achieve one or more stated purposes. <i>Note 1:</i> There are many types of systems. Examples include: general and special-purpose information systems; command, control, and communication systems; crypto modules; central processing unit and graphics processor boards; industrial/process control systems; flight control systems; weapons, targeting, and fire control systems; medical devices and treatment systems; financial, banking, and merchandising transaction systems; and social networking systems. <i>Note 2:</i> The interacting elements in the definition of system include hardware, software, data, humans, processes, facilities, materials, and naturally occurring physical entities. <i>Note 3:</i> System-of-systems is included in the definition of system. |
| system component [SP 800-53] | Discrete identifiable information technology assets that represent a building block of a system and include hardware, software, firmware, and virtual machines. |
| system element [ISO 15288] [SP 800-160 v1] | Member of a set of elements that constitute a system. <i>Note 1:</i> A system element can be a discrete component, product, service, subsystem, system, infrastructure, or enterprise. <i>Note 2:</i> Each element of the system is implemented to fulfill specified requirements. <i>Note 3:</i> The recursive nature of the term allows the term <i>system</i> to apply equally when referring to a discrete component or to a large, complex, geographically distributed system-of-systems. <i>Note 4:</i> System elements are implemented by: hardware, software, and firmware that perform operations on data / information; physical structures, devices, and components in the environment of operation; and the people, processes, and procedures for operating, sustaining, and supporting the system elements. |

| | |
|---|---|
| system-of-interest [SP 800-160 v1] | A system whose life cycle is under consideration in the context of [ISO/IEC/IEEE 15288:2015] . <i>Note:</i> A system-of-interest can be viewed as the system that is the focus of the systems engineering effort. The system-of-interest contains system elements, system element interconnections, and the environment in which they are placed. |
| system-of-systems [SP 800-160 v1] [INCOSE14] | System-of-interest whose system elements are themselves systems; typically, these entail large-scale interdisciplinary problems with multiple heterogeneous distributed systems. <i>Note:</i> In the system-of-systems environment, constituent systems may not have a single owner, may not be under a single authority, or may not operate within a single set of priorities. |
| technical risk [NASA19] | The risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements. <i>Note:</i> Technical risk is often associated with novel technologies being proposed for integration into the system-of-interest or being used in systems which interact with the system-of-interest. It can also be associated with new discoveries of inherent vulnerabilities in technologies, or with products being withdrawn from use or losing support. |
| technique | See <i>cyber resiliency technique</i> . |
| threat event [SP 800-30] | An event or situation that has the potential for causing undesirable consequences or impact. |
| threat scenario [SP 800-30] | A set of discrete threat events, associated with a specific threat source or multiple threat sources, partially ordered in time. |
| threat source [CNSSI 4009] | Any circumstance or event with the potential to adversely impact organizational operations (including mission, functions, image, or reputation), organizational assets, individuals, other organizations, or the Nation through an information system via unauthorized access, destruction, disclosure, or modification of information, and/or denial of service. |
| trustworthiness [SP 800-160 v1] | Worthy of being trusted to fulfill whatever critical requirements may be needed for a particular component, subsystem, system, network, application, mission, business function, enterprise, or other entity. |
| zero trust architecture [EO 14028] | A security model, a set of system design principles, and a coordinated cybersecurity and system management strategy based on an acknowledgement that threats exist both inside and outside traditional network boundaries. The zero trust security model eliminates implicit trust in any one element, node, or service and instead requires continuous verification of the operational picture via real-time information from multiple sources to determine access and other system responses. |

1725 APPENDIX B**1726 ACRONYMS****1727 COMMON ABBREVIATIONS**

| | |
|-------------------|--|
| ABAC | Attribute-Based Access Control |
| AFRL | Air Force Research Laboratory |
| AI | Artificial Intelligence |
| API | Application Programming Interface |
| APT | Advanced Persistent Threat |
| ARP | Address Resolution Protocol |
| ASIC | Application-Specific Integrated Circuit |
| ATT&CK | Adversarial Tactics, Techniques & Common Knowledge |
| BIA | Business Impact Analysis |
| BMS | Building Management Systems (BMS) |
| C3 | Command, Control, and Communications |
| CAN | Controller Area Network |
| CAPEC | Common Attack Pattern Enumeration and Classification |
| CCoA | Cyber Courses of Action |
| CDM | Continuous Diagnostics and Mitigation |
| CERT | Computer Emergency Response Team |
| CIS | Critical Infrastructure System |
| CJA | Crown Jewels Analysis |
| CLI | Command Line Interface |
| CMIA | Cyber Mission Impact Analysis |
| CNSS | Committee on National Security Systems |
| CNSSI | Committee on National Security Systems Instruction |
| COOP | Continuity of Operations <i>or</i> Continuity of Operations Plan |
| COTS | Commercial Off-The-Shelf |
| CPS | Cyber-Physical System or Systems |
| CRR | Cyber Resilience Review |
| CSA | Cyber Survivability Attributes |
| CSRC | Computer Security Resource Center |
| CTI | Cyber Threat Intelligence |

| | |
|----------------|--|
| CUI | Controlled Unclassified Information |
| DHS | Department of Homeland Security |
| DIB | Defense Industrial Base |
| DMZ | Demilitarized Zone |
| DNS | Domain Name System |
| DoD | Department of Defense |
| DSB | Defense Science Board |
| DSP | Digital Signal Processor |
| ECU | Embedded Control Unit |
| E-ISAC | Electricity ISAC |
| EIT | Enterprise Information Technology |
| EMS | Energy Management System |
| ERM | Enterprise Risk Management |
| FDNA | Functional Dependency Network Analysis |
| FPGA | Field-Programmable Gate Array |
| FMECA | Failure Modes, Effects, and Criticality Analysis |
| FIPS | Federal Information Processing Standard(s) |
| FISMA | Federal Information Security Modernization Act |
| FOIA | Freedom of Information Act |
| FOSS | Free and Open Source Software |
| GPS | Global Positioning System |
| HACS | Highly Adaptive Cybersecurity Services |
| HDL | Hardware Description Language |
| HMI | Human-Machine Interface |
| HVA | High-Value Asset |
| HVAC | Heating, Ventilation, and Air Conditioning |
| I&W | Indications and Warnings |
| IdAM | Identity and Access Management |
| IACD | Integrated Adaptive Cyber Defense |
| ICAM | Identity, Credential, and Access Management |
| ICS | Industrial Control System |
| ICT | Information and Communications Technology |
| IDS | Intrusion Detection System |

| | |
|----------------|---|
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| INCOSE | International Council on Systems Engineering |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| IT | Information Technology |
| ITL | Information Technology Laboratory |
| LSPE | Large-Scale Processing Environment |
| MCU | Master Control Unit |
| MFA | Multi-Factor Authentication |
| MIA | Mission Impact Analysis |
| MIL-STD | Military Standard |
| M&S | Modeling and Simulation |
| MBSE | Model-Based Systems Engineering |
| ML | Machine Learning |
| MOE | Measure of Effectiveness |
| MOP | Measure of Performance |
| MTD | Moving Target Defense |
| NASA | National Aeronautics and Space Administration |
| NDIA | National Defense Industrial Association |
| NIAC | National Infrastructure Advisory Council |
| NIST | National Institute of Standards and Technology |
| NoT | Network of Things |
| OEM | Original Equipment Manufacturer |
| OMB | Office of Management and Budget |
| OPSEC | Operations Security |
| OT | Operational Technology |
| PBX | Private Branch Exchange |
| PETE | Potential Efforts on Threat Events |
| PII | Personally Identifiable Information |
| PLC | Programmable Logic Controller |
| PPD | Presidential Policy Directive |
| RAdAC | Risk-Adaptive Access Control |

| | |
|--------------|--|
| RAID | Redundant Array of Independent Disks |
| RBAC | Role-Based Access Control |
| RMA | Reliability, Maintainability, Availability |
| RMF | Risk Management Framework |
| RMM | Resilience Management Model |
| ROI | Return on Investment |
| RTU | Remote Terminal Unit |
| RSWG | (INCOSE) Resilient Systems Working Group |
| SAE | Society of Automotive Engineers |
| SCADA | Supervisory Control and Data Acquisition |
| SCRM | Supply Chain Risk Management |
| SDN | Software Defined Networking |
| SEI | Software Engineering Institute |
| SME | Subject Matter Expert |
| SOC | Security Operations Center |
| SOW | Statement of Work |
| SP | Special Publication |
| SSE | Systems Security Engineering |
| STAMP | Systems-Theoretic Accident Model and Processes |
| STPA | System-Theoretic Process Analysis |
| TPP | Tactics, Techniques, and Procedures |
| TTX | Table Top Exercise |
| UPS | Uninterruptible Power Supply |
| VCU | Vehicle Control Unit |
| VOA | Voice of the Adversary |
| VOIP | Voice over Internet Protocol |
| VPN | Virtual Private Network |
| ZT | Zero Trust |
| ZTA | Zero Trust Architecture |

1729 APPENDIX C**1730 BACKGROUND****1731 CYBER RESILIENCY IN CONTEXT**

1732 This appendix provides background and contextual information on cyber resiliency. It
1733 describes how the definition of cyber resiliency relates to other forms of resilience; the
1734 distinguishing characteristics of cyber resiliency, including the assumptions that underpin
1735 this specialty engineering discipline; the relationship between cyber resiliency engineering and
1736 other specialty engineering disciplines; and the relationship between cyber resiliency and risk.

1737 C.1 DEFINING CYBER RESILIENCY

1738 Cyber resiliency⁸⁵ is defined as “the ability to anticipate, withstand, recover from, and adapt to
1739 adverse conditions, stresses, attacks, or compromises on systems that include cyber resources.”
1740 This definition can be applied to a variety of entities including:

- 1741 • A system;
- 1742 • A mechanism, component, or system element;
- 1743 • A shared service, common infrastructure, or system-of-systems identified with a mission or
1744 business function;
- 1745 • An organization;⁸⁶
- 1746 • A critical infrastructure sector or a region;
- 1747 • A system-of-systems in a critical infrastructure sector or sub-sector; and
- 1748 • The Nation.

1749 Cyber resiliency is emerging as a key element in any effective strategy for mission assurance,
1750 business assurance, or operational resilience. The definition of cyber resiliency is informed by
1751 definitions of the terms *resilience* and *resiliency* across various communities of interest, as
1752 illustrated in the following examples (*italics* added to highlight common goals):

⁸⁵ “Resilience” and “resiliency” are alternative spellings with resilience being more common. The term *cyber resiliency* is used in the cyber resiliency engineering framework described in this publication to avoid creating the impression that cyber resiliency engineering is a sub-discipline of resilience engineering. See [Section C.2](#) for a discussion of the relationship. The term *cyber resilience* is used by many organizations to refer to organizational resilience against cyber threats with a strong emphasis on effective implementation of good cybersecurity practices and COOP. For example, the DHS Cyber Resilience Review (CRR), which is based on the Software Engineering Institute (SEI) CERT Resilience Management Model (RMM), focuses on good practices against conventional adversaries. Discussions of cyber resilience focus on improved risk governance (e.g., making cyber risk part of enterprise risk), improved cyber hygiene to include incident response procedures and ongoing monitoring, and threat information sharing. These aspects of governance and operations are all important to an organization’s cyber preparedness strategy [[Bodeau16](#)]. However, discussions of cyber resilience in the sense of operational resilience against cyber threats, generally omit the architecture and engineering aspect, which is the focus of the cyber resiliency engineering framework and the design principles discussed in this publication.

⁸⁶ See [[SP 800-39](#)] for a discussion of the system, mission/business function, and organization levels. See [[NIST CSF](#)] for a discussion of critical infrastructure levels. See [[SP 800-37](#), [SP 800-160 v1](#)] for a discussion of system-of-systems.

- 1753 • **Resilience for the Nation:** The ability to *adapt* to changing conditions and *withstand* and
1754 rapidly *recover* from emergencies [[PPD8](#)].
- 1755 • **Critical Infrastructure Resilience:** The ability to reduce the magnitude or duration of
1756 disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon
1757 its ability to *anticipate*, *absorb*, *adapt* to, and/or rapidly *recover* from a potentially disruptive
1758 event [[NIAC10](#)].
- 1759 • **Resilience for National Security Systems:** The ability to *prepare* for and *adapt* to changing
1760 conditions and *withstand* and *recover* rapidly from disruptions. Resilience includes the
1761 ability to *withstand* and *recover* from deliberate attacks, accidents, or naturally occurring
1762 threats or incidents [[CNSSI 1253](#)] [[SP 800-37](#)].
- 1763 • **Community Resilience:** The ability of a community to *prepare* for anticipated hazards, *adapt*
1764 to changing conditions, *withstand* and *recover* rapidly from disruptions [[SP 1190](#)].
- 1765 • **Critical Infrastructure Security and Resilience:** The ability to *prepare* for and *adapt* to
1766 changing conditions and *withstand* and *recover* rapidly from disruptions. Resilience includes
1767 the ability to withstand and recover from deliberate attacks, accidents, or naturally
1768 occurring threats or incidents [[PPD21](#)].
- 1769 • **Information System Resilience:** The ability of a system to *continue* to operate under adverse
1770 conditions or stress, even if in a degraded or debilitated state, while maintaining essential
1771 operational capabilities and *recover* to an effective operational posture in a time frame
1772 consistent with mission needs [[SP 800-53](#)].
- 1773 • **Resilience in Cyberspace:** The ability to *adapt* to changing conditions and *prepare* for,
1774 *withstand*, and rapidly *recover* from disruption [[DHS10](#)].
- 1775 • **Network Resilience:** The ability of the network to provide and *maintain* an acceptable level
1776 of service in the face of various faults and challenges to normal operation [[Sterbenz06](#)].
- 1777 • **Operational Resilience:** The ability of systems to *resist*, *absorb*, and *recover* from or *adapt* to
1778 an adverse occurrence during operation that may cause harm, destruction, or loss of ability
1779 to perform mission-related functions [[CNSS 4009](#)].
- 1780 • **Resilience Engineering:** The ability to build systems that can *anticipate* and circumvent
1781 accidents, *survive* disruptions through appropriate learning and *adaptation*, and *recover*
1782 from disruptions by restoring the pre-disruption state as closely as possible [[Madni09](#)].

1783 Despite the different scope covered by each definition, there are some commonalities across
1784 the definitions. Each definition expresses a common theme of addressing those situations or
1785 conditions in which disruption, adversity, errors, faults, or failures occur. The definitions express
1786 consistent resiliency goals (shown in *italics* above) when encountering specific situations or
1787 conditions causing disruption, adversity, and faults. The definition of cyber resiliency adopted
1788 for use in this publication is consistent with the definitions cited above.

1789 C.2 DISTINGUISHING CHARACTERISTICS OF CYBER RESILIENCY

1790 Any discussion of cyber resiliency is distinguished by its focus and *a priori* threat assumptions.
1791 These are reflected in cyber resiliency constructs and engineering practices.

1793 • **Focus on the mission or business functions.**

1794 Discussions of cyber resiliency focus on capabilities supporting organizational missions or
1795 business functions in order to maximize the ability of organizations to complete critical or
1796 essential missions or business functions despite an adversarial presence in their systems and
1797 infrastructure threatening mission-critical systems and system components. This is in
1798 contrast to focusing on the protection of information or on ensuring capabilities in a non-
1799 adversarial environment. It is also in contrast to focusing on ensuring the resilience of
1800 system elements or of constituent systems in a system-of-systems. From the perspective of
1801 cyber resiliency, system elements or constituent systems that are less critical to mission or
1802 business effectiveness can be sacrificed to contain a cyber attack and maximize mission
1803 assurance.

1804 • **Assume a changing environment.**

1805 Discussions related to cyber resiliency assume ongoing and episodic changes in the threat
1806 environment, the operational environment, and the technical environment. APT actors learn
1807 from experience. Their motives can change in response to economic and political factors,
1808 and their TTPs can become commodity tools for lower-level actors. The ways technology is
1809 used by individuals and organizations change due to events such as the COVID-19 pandemic,
1810 broader or more cost-effective availability of services such as cloud computing, and growing
1811 familiarity with and acceptance of newer technologies. The technical environment continues
1812 to evolve, such as with the rapid convergence of information technology and operational
1813 technology, the increasing maturity of artificial intelligence and machine learning, and the
1814 transition to zero trust architectures. These changes can interact in many ways, increasing
1815 the complexity and reducing the transparency of systems, services, infrastructures, and
1816 ecosystems. From the perspective of cyber resiliency, changes can simultaneously present
1817 risks and opportunities for risk reduction. Risk management needs to consider differences in
1818 scale and time frame.

1819 • **Focus on the effects of the advanced persistent threat.**

1820 The definition of cyber resiliency encompasses all threats to systems containing cyber
1821 resources, whether such threats are cyber or non-cyber (e.g., kinetic) in nature. However,
1822 cyber resiliency analysis focuses on the effects that the APT can have on the system-of-
1823 interest and, thereby, on the missions or business functions, organization, or external
1824 stakeholders.

1825 In addition to immediately detectable effects (e.g., destruction of data, malfunction of a
1826 CPS, denial of service), the APT can produce effects that are detectable only after extended
1827 observation or forensic analysis of the system-of-interest (e.g., escalation of privileges,
1828 modification or fabrication of data or services, exfiltration of data). Consideration of cyber
1829 resiliency in systems security engineering seeks to mitigate such effects, independent of
1830 when or whether they may be detected.

1831 The resources associated with the APT, its stealthy nature, its persistent focus on the target
1832 of interest, and its ability to adapt in the face of defender actions make it a highly dangerous
1833 threat. Moreover, the APT can take advantage of or make its behavior appear to result from
1834 other forms of adversity, including human error, structural failure, or natural disaster. By
1835 focusing on APT activities and their potential effects, systems engineers produce systems
1836 that can anticipate, withstand, recover from, and adapt to a broad and diverse suite of
1837 adverse conditions and stresses on systems containing cyber resources.

1838 • **Assume the adversary will compromise or breach the system or organization.**

1839 A fundamental assumption in any discussion of cyber resiliency is that a sophisticated
1840 adversary cannot always be kept out of a system or be quickly detected and removed from
1841 that system, despite the quality of the system design, the functional effectiveness of the
1842 security components, and the trustworthiness of the selected components. This assumption
1843 acknowledges that modern systems are large and complex entities, and adversaries will
1844 always be able to find and exploit weaknesses and flaws in the systems (e.g., unpatched
1845 vulnerabilities, misconfigurations), environments of operation (e.g., social engineering, user
1846 vulnerability), and supply chains. As a result, a sophisticated adversary can penetrate an
1847 organizational system and achieve a presence within the organization's infrastructure.

1848 • **Assume the adversary will maintain a presence in the system or organization.**

1849 Any discussion of cyber resiliency assumes that the adversary presence may be a persistent
1850 and long-term issue and recognizes that the stealthy nature of the APT makes it difficult for
1851 an organization to be certain that the threat has been eradicated. It also recognizes that the
1852 ability of the APT to adapt implies that previously successful mitigations may no longer be
1853 effective. Finally, it recognizes that the persistent nature of the APT means that even if an
1854 organization has succeeded in eradicating its presence, it may return. In some situations, the
1855 best outcome that an organization can achieve is containing the adversary's malicious code
1856 or slowing its lateral movement across the system (or transitively across multiple systems)
1857 long enough that the organization is able to achieve its primary mission prior to losing its
1858 critical or essential mission capability.

1859 **C.3 RELATIONSHIP WITH OTHER SPECIALITY ENGINEERING DISCIPLINES**

1860 Cyber resiliency is an aspect of trustworthiness, as are safety, system resilience, survivability,
1861 reliability, and security.⁸⁷ Cyber resiliency concepts and engineering practices assume a basic
1862 foundation of security and reliability. Many cyber resiliency techniques use or rely on security,
1863 reliability, resilience, and fault-tolerance mechanisms, and many cyber resiliency techniques and
1864 design principles are relevant to zero trust architectures. The concepts and engineering
1865 practices described in this publication build on work in the specialty engineering disciplines of
1866 resilience engineering and dependable computing, including survivability engineering and fault
1867 tolerance.

1868 • **Safety**

1869 Safety is defined as "freedom from conditions that can cause death, injury, occupational
1870 illness, damage to or loss of equipment or property, or damage to the environment" [[SP](#)
1871 [800-82](#)]. Safety engineering focuses on identifying unacceptable system behaviors,
1872 outcomes, and interactions and helping to ensure that the system does not enter an
1873 unacceptable state (i.e., a state in which such behaviors, interactions, or outcomes are
1874 possible, thus creating or being an instance of a condition that can cause one of the harms
1875 identified above). System safety engineering is based on analytic processes rather than
1876 design principles or constructs.

⁸⁷ Trustworthiness requirements can include attributes of reliability, dependability, performance, resilience, safety, security, and survivability under a range of potential adversity in the form of disruptions, hazards, and threats [[SP](#)
[800-53](#)].

1877 [SP 800-160 v1] states that “the system aspects of secure operation may intersect,
1878 complement, or be in direct conflict or contradiction with those of safe operation of the
1879 system.” A similar statement may be made with respect to cyber-resilient operations. The
1880 set of unacceptable states defined by safety engineering may constitute a constraint on
1881 cyber resiliency solutions or may be used in trade-off analyses. As part of achieving a specific
1882 cyber resiliency objective, such as [Continue](#) or [Reconstitute](#),⁸⁸ a system may need to operate
1883 transiently in an unsafe (or insecure) state, depending on how stakeholders prioritize and
1884 trade off required system properties and behaviors.

1885 • **Security**

1886 The relationship between cyber resiliency and security depends on which definition of
1887 security is considered. [SP 800-37] defines security as:

1888 “A condition that results from the establishment and maintenance of
1889 protective measures that enable an organization to perform its mission
1890 or critical functions despite risks posed by threats to its use of systems.
1891 Protective measures may involve a combination of deterrence,
1892 avoidance, prevention, detection, recovery, and correction that should
1893 form part of the organization’s risk management approach.”

1894 This definition of security overlaps with but does not subsume cyber resiliency since
1895 “protective measures,” as listed in the definition, do not fully cover risk management
1896 strategies related to cyber resiliency.⁸⁹

1897 Cyber resiliency engineering may be viewed as a specialty discipline of systems security
1898 engineering. [SP 800-160 v1] defines security as the “freedom from those conditions that
1899 can cause loss of assets with unacceptable consequences.”⁹⁰ In that context, security is
1900 concerned with the protection of assets and is primarily oriented to the concept of asset
1901 loss.⁹¹ It includes but is not limited to cybersecurity.⁹² Cyber resiliency engineering is
1902 oriented toward capabilities and harms to systems containing cyber resources. This
1903 orientation is consistent with the concept of asset loss since a capability is a form of
1904 intangible asset. As noted above, cyber resiliency engineering focuses on capabilities that
1905 support missions or business functions and on the effects of adversarial actions on systems.

⁸⁸ See [Section 2.1.2](#).

⁸⁹ See [Section C.4](#).

⁹⁰ This is a broader construction than what appears in [FIPS 199]. In accordance with [FISMA], FIPS 199 defines three security objectives for information and information systems: confidentiality, integrity, and availability. A loss of confidentiality is the unauthorized disclosure of information; a loss of integrity is the unauthorized modification or destruction of information; and a loss of availability is the disruption of access to or use of information or an information system.

⁹¹ The term *protection*, in the context of systems security engineering, has a very broad scope and is primarily a control objective that applies across all asset types and corresponding consequences of loss. Therefore, the system protection capability is a system control objective and a system design problem. The solution to the problem is optimized through a balanced proactive and reactive strategy that is not limited to prevention. The strategy includes avoiding, detecting, minimizing (i.e., limiting, containing, restricting), responding to, recovering from, and forecasting or predicting asset loss and consequences [SP 800-160 v1].

⁹² Cybersecurity is defined as “the process of protecting information by preventing, detecting, and responding to attacks” [NIST CSF] or as the “prevention of damage to, protection of, and restoration of computers, electronic communications systems, electronic communications services, wire communication, and electronic communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation” [OMB A-130].

1906 While [SP 800-160 v1] views security, asset loss, and protection broadly, much of the
1907 security literature and many security practitioners focus narrowly on the security objectives
1908 of confidentiality, integrity, and availability of information and information systems [FIPS
1909 199].⁹³ Cyber resiliency engineering considers a broader range of cyber effects (i.e., effects
1910 in cyberspace) than the loss of confidentiality, integrity, or availability of information or of
1911 system services. Cyber effects of concern to cyber resiliency engineering do include the
1912 effects of concern to security, including service degradation and denial or interruption of
1913 service; non-disruptive modification, fabrication, corruption, or destruction of information
1914 resources; and unauthorized disclosure of information. In addition, they include the
1915 usurpation or unauthorized use of resources, even when such use is non-disruptive to the
1916 system-of-interest; reduced confidence in system capabilities, which can alter system usage
1917 behavior; and alterations in behaviors that affect external systems, which can result in
1918 cascading failures beyond the system-of-interest.

1919 As noted above, cyber resiliency concepts and engineering practices assume a foundation of
1920 security. Some cyber resiliency techniques⁹⁴ rely on the correct and effective application of
1921 security controls. Some cyber resiliency design principles⁹⁵ adapt or are strongly aligned
1922 with the security design principles described in [SP 800-160 v1].

1923 • **Zero Trust**

1924 Zero trust is a security paradigm for enterprise computing with extensions to other
1925 computing environments (e.g., operational technology networks). A zero trust architecture
1926 (ZTA) can be characterized as a security model, a set of system design principles, and a
1927 coordinated cybersecurity and system management strategy based on an acknowledgement
1928 that threats exist both inside and outside of traditional network boundaries [EO 14028].
1929 Thus, cyber resiliency and zero trust share assumptions about cyber threats. However,
1930 where cyber resiliency is motivated by mission assurance in a contested cyber environment,
1931 zero trust is focused on preventing unauthorized access to data and services [SP 800-207].

1932 Cyber resiliency includes a large number of constructs with the assumption that these will
1933 be interpreted, prioritized, and down-selected for a given organization, mission or business
1934 function, or system-of-interest. Thus, two architectures can be equally cyber-resilient while
1935 providing radically different capabilities. By contrast, the expectation for a ZTA is that it will
1936 provide comprehensive security monitoring, granular risk-based access controls, and system
1937 security automation [EO 14028]. As noted in [Section D.4](#) and [Section D.5](#), multiple cyber
1938 resiliency techniques, approaches, and design principles can be integrated into the design
1939 and deployment of a ZTA, and some cyber resiliency techniques (e.g., [Segmentation](#),
1940 [Privilege Restriction](#)) are essential to ZT.

1941 • **Resilience Engineering and Survivability Engineering**

1942 The specialty disciplines of resilience engineering and survivability engineering address
1943 system resilience whether or not the system-of-interest contains cyber resources. Cyber
1944 resiliency concepts and engineering practices assume that some of the system elements are
1945 cyber resources. Resilience engineering is “the ability to build systems that can anticipate
1946 and circumvent accidents, survive disruptions through appropriate learning and adaptation,

⁹³ Note that [SP 800-160 v1] adapts these security objectives to be more broadly applicable.

⁹⁴ See [Section 2.1.3](#).

⁹⁵ See [Section 2.1.4](#).

1947 and recover from disruptions by restoring the pre-disruption state as closely as possible”
 1948 [Madni07, Madni09]. Survivability engineering can be viewed as the subset of systems
 1949 engineering concerned with minimizing the impact of environmental disturbances on
 1950 system performance. Survivability is defined as:

1951 ...the ability of a system to minimize the impact of a finite-duration
 1952 disturbance on value delivery (i.e., stakeholder benefit at cost),
 1953 achieved through the reduction of the likelihood or magnitude of a
 1954 disturbance; the satisfaction of a minimally acceptable level of value
 1955 delivery during and after a disturbance; and/or a timely recovery
 1956 [Richards09].

1957 Cyber resiliency engineering draws upon concepts and design principles from resilience
 1958 engineering and survivability engineering. However, as discussed further in [Section D.4](#), the
 1959 threat model for cyber resiliency differs from the model typically used in these specialty
 1960 engineering disciplines, which assume detectable disruptions. The concepts and design
 1961 principles for survivability and resilience are adapted or extended to reflect malicious cyber
 1962 activities that can remain undetected for extended periods.

- 1963 • **Cyber Survivability**

1964 Cyber survivability is defined in [Pitcher19], [Pitcher21], and [JCS17] as “the ability of
 1965 warfighter systems to prevent, mitigate, recover from and adapt to adverse cyber-events
 1966 that could impact mission-related functions by applying a risk-managed approach to achieve
 1967 and maintain an operationally-relevant risk posture, throughout its life cycle.” Cyber
 1968 survivability is defined for warfighter systems (e.g., weapons systems, supporting critical
 1969 infrastructures), and in that context, is conceptually identical to cyber resiliency.

1970 Engineering for cyber survivability focuses on defining and evaluating Cyber Survivability
 1971 Attributes (CSAs), which are system capabilities that support and serve as indicators of cyber
 1972 survivability. The CSAs align with the cyber resiliency goals: CSA01-06 with [Anticipate](#),
 1973 CSA07-08 with [Withstand](#), CSA09 with [Recover](#), and CSA10 with [Adapt](#). Many CSAs depend
 1974 on the same security measures and other functionality as cyber resiliency techniques and
 1975 implementation approaches (e.g., performance monitoring; identity, credential, and access
 1976 management; and logging and auditing). Systems engineers can employ cyber resiliency
 1977 techniques in the design and implementation of a system to provide the CSA-required
 1978 functionality or to make that functionality more effective against threat actions.⁹⁶

- 1979 • **Reliability**

1980 Reliability is defined as “the ability of a system or component to function under stated
 1981 conditions for a specified period of time” [IEEE90]. Reliability engineering shares many
 1982 analytic techniques with safety engineering but focuses on failures of systems or system
 1983 components rather than on potential harms. Cyber resiliency engineering assumes that
 1984 reliability, including the consideration of degradation and failure, is addressed in the overall
 1985 systems engineering process. The threat model, including the stated conditions for
 1986 reliability, typically does not include deliberate adversarial behavior and necessarily
 1987 excludes new and unanticipated attack methods developed by advanced adversaries.

⁹⁶ The CSA tool created by the Air Force Research Laboratory (AFRL) [[Reilly19](#)] captures relationships between controls and control enhancements in [[SP 800-53](#)], which support cyber resiliency (see [Table E.1](#)) and the CSAs. The CSA tool also captures the mappings of cyber resiliency controls and implementation approaches to ATT&CK techniques (see [Appendix F](#)).

- 1988 • **Fault Tolerance**
- 1989 A fault-tolerant system is one with “the built-in capability to provide continued, correct execution of its assigned function in the presence of a hardware and/or software fault” [SP 1990 800-82]. Classes of faults include development faults, physical faults, and interaction faults.
- 1991 Faults can be characterized by the phase of creation or occurrence whether they are 1992 internal or external to a system, natural or human-made, or in hardware, software, 1993 persistence, and properties related to human-made faults [Avizienis04]. An advanced 1994 adversary can cause, emulate, or take advantage of a fault. Cyber resiliency engineering 1995 draws some techniques or approaches⁹⁷ from fault tolerance and leverages these 1996 capabilities while assuming that the actions of an advanced adversary may go undetected.
- 1997
- 1998 The analytic processes and practices related to cyber resiliency are intended to be integrated 1999 with those for other specialty engineering disciplines, including security, systems engineering, 2000 resilience engineering, safety, cybersecurity, and mission assurance. Examples of analytic 2001 practices from these disciplines include:
- 2002 • **Security, Information Security, and Cybersecurity:** Operations security (OPSEC) analysis (see 2003 SC-38 in [SP 800-53]), information security risk analysis [SP 800-30], coverage analysis with 2004 respect to a taxonomy of attack events or TTPs [DHSCDM], attack tree or attack graph 2005 analysis, attack surface analysis, adversary emulation [MITRE21], and Red Team or 2006 penetration testing analysis
- 2007 • **Resilience Engineering:** Criticality Analysis [IR 8179], Mission Impact Analysis (MIA), 2008 Business Impact Analysis (BIA) [SP 800-34], fault tree analysis, and Failure Modes, Effects, 2009 and Criticality Analysis (FMECA)
- 2010 • **Systems Engineering:** Modeling and simulation (M&S), model-based systems engineering 2011 (MBSE), and Functional Dependency Network Analysis (FDNA)
- 2012 • **Safety:** Fault tree analysis, FMECA, System-Theoretic Process Analysis (STPA), and Systems- 2013 Theoretic Accident Model and Processes (STAMP) [Leveson12]
- 2014 • **Mission Assurance:** Crown Jewels Analysis (CJA), mission thread analysis, cyber mission 2015 impact analysis (CMIA), and supply chain risk management (SCRM) analysis [SP 800-161]
- 2016 These existing analytic practices are extensible (and in practice have been extended) to include 2017 cyber resiliency concepts and concerns, particularly the growing concern that an advanced 2018 adversary can establish a covert and persistent presence on a specific system-of-interest, 2019 enabling system, or another system in the environment of operation of the system-of-interest. 2020 Additional analytic practices include structured analysis of the system architecture and design 2021 with respect to cyber resiliency design principles, techniques, and approaches and adaptation of 2022 coverage analysis to include effects on adversary activities described in [Appendix F](#).
- 2023 **C.4 RELATIONSHIP BETWEEN CYBER RESILIENCY AND RISK**
- 2024 Cyber resiliency solutions are intended to reduce the risk to missions or business functions, 2025 organizations, and individuals that depend on systems containing cyber resources. This cyber 2026 risk arises in several ways. For example, cyber resources and the systems that incorporate those

⁹⁷ See [Section 2.1.3](#).

2027 resources are increasingly complex, so their behavior and properties in the presence of adversity
2028 (or even under expected levels of stress) can be difficult to predict. Software generally includes
2029 vulnerabilities and weaknesses, which can make it fragile and subject to exploitation by an
2030 adversary. Additionally, the presence of resources in cyberspace exposes them to cyber
2031 attacks.⁹⁸

2032 Cyber resiliency solutions are intended to reduce the risk of depending on systems that contain
2033 cyber resources by reducing the extent of the harm from threat events,⁹⁹ the likelihood of the
2034 occurrence of threat events, and the likelihood that threat events will cause harm.¹⁰⁰ The risk
2035 model for cyber resiliency identifies the types of threat events and the classes of harm of
2036 interest to systems security engineers concerned with cyber resiliency. The extent of potential
2037 risk mitigation due to a cyber resiliency solution can be analyzed and assessed in the context of
2038 that risk model.

2039 The *risk model* for cyber resiliency builds on risk models for security, cybersecurity, resilience
2040 engineering, and survivability. However, the cyber resiliency risk model emphasizes the APT and
2041 the effects on missions and organizations of malicious cyber activities or of harm to systems that
2042 include cyber resources. Thus, the threat model and the consequence model components of the
2043 cyber resiliency threat model have distinctive characteristics.

2044 The *threat model* for cyber resiliency encompasses conventional security threat models that
2045 consider threat sources, including accident and human error, structural failure of system
2046 elements or supporting infrastructures, natural disasters, and deliberate human actions
2047 (including those by malicious insiders). Similarly, the threat model for cyber resiliency
2048 encompasses typical cybersecurity risk models.¹⁰¹ However, the cyber resiliency threat model
2049 emphasizes the APT as a primary or secondary threat source. As a primary threat source,
2050 sophisticated adversaries execute cyber campaigns that can involve multiple systems and
2051 organizations and extend for periods of months or even years.¹⁰² In addition, these adversaries
2052 can use TTPs typical of less sophisticated cyber threat actors. As a secondary threat source, the
2053 APT can take advantage of threat events due to infrastructure failure or natural disasters and
2054 imitate or leverage human error or the loss of component reliability. Therefore, when cyber
2055 resiliency engineering analysis considers a potential disruption with a non-adversarial source,
2056 that analysis includes looking for ways in which the APT could take advantage of the disruption.

⁹⁸ The risk due to the potential for a cyber attack (i.e., an attack via cyberspace, targeting an organization's use of cyberspace for the purpose of disrupting, disabling, destroying, or maliciously controlling a computing environment or infrastructure; destroying the integrity of data; or stealing controlled information [[SP 800-39](#)]) is also referred to as cybersecurity risk [[NIST CSF](#)].

⁹⁹ The term *threat event* refers to an event or situation that has the potential for causing undesirable consequences or impacts. Threat events can be caused by either adversarial or non-adversarial threat sources [[SP 800-30](#)].

¹⁰⁰ While many different risk models are potentially valid and useful, three elements are common across most models: the likelihood of occurrence, the likelihood of impact, and the level of the impact [[SP 800-30](#)].

¹⁰¹ [[EO 13800](#)] states that "cybersecurity risk management comprises the full range of activities undertaken to protect IT and data from unauthorized access and other cyber threats, to maintain awareness of cyber threats, to detect anomalies and incidents adversely affecting IT and data, and to mitigate the impact of, respond to, and recover from incidents." While the term *cyber threat* is used without definition in such sources as [[EO 13800](#)], [[ODNI17](#)], [[DSB13](#)], and [[DHSCDM](#)], its use (without the qualification of "advanced") generally implies that the cyber threat actor attacks via cyberspace.

¹⁰² Activities and threat events can be obtained from [[MITRE18](#)] or [[SP 800-30](#)] with augmentation or additional detail from other sources. The stages or phases of a cyber attack can be obtained from [[MITRE18](#)] or [[ODNI17](#)].

2057 The *consequence model* for cyber resiliency encompasses consequences to information and
2058 information systems (i.e., a loss of confidentiality, integrity, or availability, as defined in [[FIPS](#)
2059 [199](#)]). These general consequences can be translated into more specific harms to information
2060 and systems that include or are enabled by cyber resources: degraded or disrupted functionality
2061 or performance; modified, corrupted, or fabricated information; usurped or misused system
2062 resources; or exfiltrated or exposed information. However, the consequence model for cyber
2063 resiliency also considers the potential consequences to the missions or business functions
2064 supported by the system, to the organization, and sometimes to other stakeholders (e.g.,
2065 individuals whose personal information may be exfiltrated or exposed, members of the public
2066 affected by environmental harms resulting from failure of a critical infrastructure system). In
2067 general, a cyber resiliency solution identified and implemented for a given scope is intended to
2068 reduce risks at the next level; for example, implementing a solution at the system level can
2069 mitigate risks to mission or business function.

2070 Consequences to a mission or business function or to an organization can be defined in terms of
2071 impacts on the performance of required functions or on preserving required properties. The risk
2072 model for cyber resiliency, therefore, aligns well with mission risk models [[Musman18](#)]. It can
2073 also be used in conjunction with risk models that represent quality properties, such as security,
2074 survivability, and resilience.¹⁰³

- 2075 • **Security:** The threat model for cyber resiliency encompasses the security threat model but
2076 emphasizes the APT. Depending on how broadly (e.g., all stakeholder trustworthiness
2077 concerns) or narrowly (e.g., specific stakeholder concerns for confidentiality, integrity, or
2078 availability) security is construed, the cyber resiliency consequence model can coincide with
2079 or include the security consequence model. The consequence model requires the systems
2080 engineers analyzing risks to view the system-of-interest in terms of how its environment of
2081 operation¹⁰⁴ imposes constraints and also how adversity involving cyber resources and,
2082 consequently, the system-of-interest affect that environment.
- 2083 • **Resilience engineering and survivability:** The threat model for resilience engineering and
2084 survivability focuses on an event or a set of circumstances that disrupts performance.
2085 Survivability considers finite-duration events, while resilience engineering also considers
2086 multiple or repeated events and changes in the operational environment. In either case, the
2087 threat model implicitly assumes that the event or its immediate consequences can be
2088 detected. The threat model for cyber resiliency, by contrast, assumes that an advanced
2089 adversary can operate covertly in the system for an extended period before causing a
2090 detectable disruption. The consequence model is also different. Adversary-caused harms,
2091 such as the fabrication of user accounts or the exfiltration of sensitive information, may be
2092 non-disruptive. Disruption of normal system performance may, in fact, result from defensive
2093 actions taken after such harms are detected (e.g., removing compromised or suspect
2094 components from the system). Thus, the consequence model for cyber resiliency
2095 encompasses the consequence model for resilience and survivability.

¹⁰³ *Quality properties* are emergent properties of systems that may include safety, security, maintainability, resilience, reliability, availability, agility, and survivability [[SP 800-160 v1](#)]. These properties are also referred to as *systemic properties* across many engineering domains.

¹⁰⁴ See Figure 2 in [[SP 800-160 v1](#)].

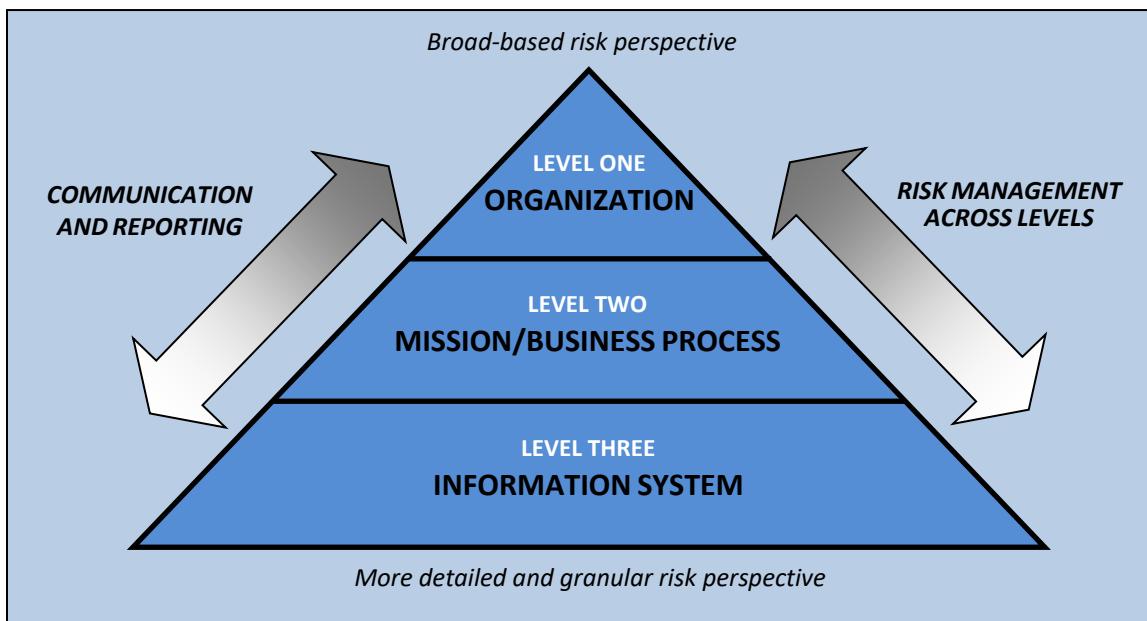
2096 **APPENDIX D**2097 **CYBER RESILIENCY CONSTRUCTS**

2098 ENGINEERING FRAMEWORK CONSTRUCTS AND RELATIONSHIPS

2099 This appendix provides an in-depth description of the cyber resiliency constructs that are
 2100 part of the cyber resiliency engineering framework. The constructs include cyber resiliency
 2101 goals, objectives, techniques, implementation approaches, strategic design principles, and
 2102 structural design principles. The appendix also describes the relationships among constructs to
 2103 assist stakeholders in the application of the constructs.

2104 **D.1 CYBER RESILIENCY GOALS**

2105 Cyber resiliency, similar to security, is a concern at multiple levels in an organization. The cyber
 2106 resiliency goals (i.e., anticipate, withstand, recover, and adapt) support the linkage between the
 2107 risk management decisions at the mission or business process and system levels and the
 2108 organization's risk management strategy [[SP 800-39](#)].

2119 **FIGURE D-1: ORGANIZATION-WIDE RISK MANAGEMENT APPROACH**

2121 To address cyber resiliency, an organization's risk management strategy needs to include its
 2122 threat-framing with respect to cyber threats, its strategies for achieving cyber resiliency goals,
 2123 and its choice of factors to use when prioritizing and interpreting cyber resiliency objectives at
 2124 the mission or business process level and at the system level. Strategies for achieving cyber
 2125 resiliency goals include:

- 2126 • **Anticipate:** Deterrence, avoidance, and prevention are strategies for anticipating potential
 2127 threats. Other strategies include planning (i.e., identifying available resources and creating
 2128 plans for using those resources if a threat materializes), preparation (i.e., changing the set of
 2129 available resources and exercising plans), and morphing (i.e., changing the system on an
 2130 ongoing basis in order to change the attack surface).

- **Withstand:** Strategies for withstanding the realization of potential threats, even when those threats are not detected, include absorption (i.e., accepting some level of damage to a given set of system elements, taking actions to reduce the impacts to other system elements or to the system as a whole, and repairing damage automatically), deflection (i.e., transferring threat events or their effects to different system elements or to systems other than those that were targeted or initially affected), and discarding (i.e., removing system elements or even a system as a whole based on indications of damage and either replacing those elements or enabling the system or mission or business process to operate without them).
- **Recover:** Strategies for recovery include reversion (i.e., replicating a prior state that is known to be acceptable), reconstitution (i.e., replicating critical and supporting functions to an acceptable level or using existing system resources), and replacement (i.e., replacing damaged, suspect, or selected system elements with new ones or repurposing existing system elements to serve different functions in order to perform critical and supporting functions, possibly in different ways). Detection can support the selection of a recovery strategy. However, a system can apply these strategies independent of detection to change the attack surface.
- **Adapt:** Strategies for adaptation include correction (i.e., removing or applying new controls to compensate for identified vulnerabilities or weaknesses), hardening (i.e., reducing or manipulating attack surfaces), and reorientation (i.e., proactively orienting controls, practices, and capabilities to prospective, emerging, or potential threats). These strategies may result in redefinition (i.e., changing the system's requirements, architecture, design, configuration, acquisition processes, or operational processes).

The organizational risk management strategy includes aspects that can limit the set of cyber resiliency solutions it will consider. These aspects include:¹⁰⁵

- The organization's risk mitigation philosophy (e.g., compliance with standards of good practice, incorporating state-of-the-art technologies and making trade-offs between standards of good practice and leading-edge protection technologies, pushing the state-of-the-art through cyber defense DevOps)
- Dependencies and interactions among the organization's programs, initiatives, and other efforts at multiple levels that involve investment in, transition to, or use of cyber technologies (e.g., transition to a zero trust architecture)
- The types of external coordination in which the organization will participate (e.g., consumer of threat intelligence, bi-directional threat information-sharing, cooperation or coordination to counter threats, collaboration)
- Whether and how deception can be used

D.2 CYBER RESILIENCY OBJECTIVES

Table D-1 provides representative examples of sub-objectives for each cyber resiliency objective defined in Table 3. A sub-objective motivates the definition of requirements and the selection and tailoring of controls. The representative sub-objectives can be used as a starting point for eliciting restatements of objectives and for defining metrics, as illustrated in the table. The

¹⁰⁵ See [Bodeau16].

2171 representative sub-objectives, suitably restated for the system-of-interest, can be further
 2172 decomposed into capabilities of (or activities performed by) that system, and threshold and
 2173 objective values can be stated.¹⁰⁶

2174

TABLE D-1: CYBER RESILIENCY SUB-OBJECTIVES

| OBJECTIVE | REPRESENTATIVE SUB-OBJECTIVES | REPRESENTATIVE EXAMPLES OF METRICS |
|---|--|--|
| PREVENT OR AVOID Definition: Preclude the successful execution of an attack or the realization of adverse conditions. | <ul style="list-style-type: none"> Apply basic protection measures and controls tailored to the risks of the system-of-interest. Limit exposure to threat events. Decrease the adversary's perceived benefits. Modify configurations based on threat intelligence. | <ul style="list-style-type: none"> Time to patch or to apply configuration changes. Percentage of resources for which configuration changes are randomly made. Percentage of resources for which lifespan limits are applied. Percentage of sensitive data assets that are encrypted. Adversary dwell time in a deception environment. Percentage of resources to which more restrictive privileges are automatically applied in response to threat indicators. |
| PREPARE Definition: Maintain a set of realistic courses of action that address predicted or anticipated adversity. | <ul style="list-style-type: none"> Create and maintain cyber courses of action. Maintain the resources needed to execute cyber courses of action. Validate the realism of cyber courses of action using testing or exercises. | <ul style="list-style-type: none"> Number of cyber courses of action (CCoAs) in the cyber playbook. Percentage of identified threat types, categories of threat actions, or TTPs (with reference to an identified threat model) addressed by at least one CCoA in the cyber playbook. Percentage of cyber resources that are backed up. Time since the last exercise of alternative communications paths. Percentage of administrative staff who have been trained in their CCoA responsibilities. Time since last (random, scheduled) exercise or simulation of one or more CCoAs. |
| CONTINUE Definition: Maximize the duration and viability of essential mission or business functions during adversity. | <ul style="list-style-type: none"> Minimize the degradation of service delivery. Minimize interruptions in service delivery. Ensure that ongoing functioning is correct. | <ul style="list-style-type: none"> Time to perform mission or business function damage assessment. Length of time performance of specified mission or business function remained below acceptable levels. Time from initial disruption to availability (at minimum level of acceptability) of essential functions. Percentage of essential data assets for which data quality has been validated. Percentage of essential processing services for which correctness of functioning has been validated. |
| CONSTRAIN Definition: Limit damage from adversity. | <ul style="list-style-type: none"> Identify potential damage. Isolate resources to limit future or further damage. Move resources to limit future or further damage. | <ul style="list-style-type: none"> Percentage of critical components that employ anti-tamper, shielding, and power line filtering. Time from initial indication or warning to completion of scans for potentially damaged resources. |

¹⁰⁶ See [Bodeau18b].

| OBJECTIVE | REPRESENTATIVE SUB-OBJECTIVES | REPRESENTATIVE EXAMPLES OF METRICS |
|---|---|--|
| | <ul style="list-style-type: none"> Change or remove resources and how they are used to limit future or further damage. | <ul style="list-style-type: none"> Time from initial indication or warning to the completion of component isolation. Time from initial indication or warning to the completion of resource relocation. Time from initial indication or warning to the completion of switch to an alternative. |
| RECONSTITUTE Definition: Restore as much mission or business functionality as possible after adversity. | <ul style="list-style-type: none"> Identify untrustworthy resources and damage.¹⁰⁷ Restore functionality. Heighten protections during reconstitution. Determine the trustworthiness of restored or reconstructed resources. | <ul style="list-style-type: none"> Time to identify unavailable resources and represent damage in status visualization. Time between the initiation of recovery procedures and the completion of documented milestones in the recovery, contingency, or continuity of operations plan. Percentage of cyber resources for which access control is maintained throughout the recovery process. Percentage of cyber resources for which additional auditing or monitoring is applied during and after the recovery process. Time to bring a backup network intrusion detection system online. Percentage of reconstituted cyber resources that are placed in a restricted enclave for a period after reconstitution. Percentage of restored or reconstructed (mission-critical, security-critical, supporting) data assets for which data integrity/quality is checked. |
| UNDERSTAND Definition: Maintain useful representations of mission and business dependencies and the status of resources with respect to possible adversity. | <ul style="list-style-type: none"> Understand adversaries. Understand dependencies on and among systems containing cyber resources. Understand the status of resources with respect to threat events. Understand the effectiveness of security controls and controls supporting cyber resiliency. | <ul style="list-style-type: none"> Time between the receipt of threat intelligence and the determination of its relevance. Adversary dwell time in deception environment. Time since the most recent refresh of mission dependency or functional dependency map. Time since the last cyber table-top exercise, Red Team exercise, or execution of controlled automated disruption. Percentage of system elements for which failure or the indication of potential faults can be detected. Percentage of cyber resources monitored. Number of attempted intrusions stopped at a network perimeter. Average length of time to recover from incidents. |
| TRANSFORM Definition: Modify mission or business | <ul style="list-style-type: none"> Redefine mission or business process threads for agility. Redefine mission or business functions to mitigate risks. | <ul style="list-style-type: none"> Percentage of mission or business process threads that have been analyzed with respect to common dependencies and potential single points of failure. Percentage |

¹⁰⁷ Damage need not be identified with specific resources. For example, degraded service can be systemic. Resources (e.g., processes) can be untrustworthy even if they appear to be performing correctly.

| OBJECTIVE | REPRESENTATIVE SUB-OBJECTIVES | REPRESENTATIVE EXAMPLES OF METRICS |
|---|---|--|
| functions and supporting processes to handle adversity and address environmental changes more effectively. | | <p>of mission or business process threads for which alternative courses of action are documented.</p> <ul style="list-style-type: none"> Percentage of essential functions for which no dependencies on resources shared with nonessential functions can be identified. Percentage of problematic data feeds to which risk mitigations have been applied since last analysis. |
| RE-ARCHITECT Definition: Modify architectures to handle adversity and address environmental changes more effectively. | <ul style="list-style-type: none"> Restructure systems or sub-systems to reduce risks. Modify systems or sub-systems to reduce risks. | <ul style="list-style-type: none"> Size of the (hardware, software, supply chain, user, privileged user) attack surface. Percentage of system components for which provenance can be determined. Percentage of system components that can be selectively isolated. Percentage of cyber resources for which custom analytics have been developed. Percentage of mission-critical components for which one or more custom-built alternatives are implemented. |

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D.3 CYBER RESILIENCY TECHNIQUES

2178 This section provides definitions for cyber resiliency *techniques*, one of the fundamental cyber
 2179 resiliency constructs, which also include goals, objectives, approaches, and design principles.
 2180 The objectives support goals, the techniques support objectives, the approaches support
 2181 techniques, and the design principles support the realization of the goals and objectives. The
 2182 relationship among the cyber resiliency constructs, including specific mapping tables for the
 2183 constructs, is provided in [Appendix F](#). [Table D-2](#) lists each cyber resiliency technique and its
 2184 purpose. [Table D-3](#) identifies potential interactions (e.g., synergies, conflicts) between cyber
 2185 resiliency techniques.

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TABLE D-2: CYBER RESILIENCY TECHNIQUES

| TECHNIQUE | PURPOSE |
|---|---|
| ADAPTIVE RESPONSE Definition: Implement agile courses of action to manage risks. | Optimize the ability to respond in a timely and appropriate manner to adverse conditions, stresses, attacks, or indicators of these, thus maximizing the ability to maintain mission or business operations, limit consequences, and avoid destabilization. |
| ANALYTIC MONITORING Definition: Monitor and analyze a wide range of properties and behaviors on an ongoing basis and in a coordinated way. | Maximize the ability to detect potential adverse conditions; reveal the extent of adverse conditions, stresses, or attacks; identify potential or actual damage, and investigate adversary TTPs. Provide the data needed for situational awareness. |

| TECHNIQUE | PURPOSE |
|--|---|
| CONTEXTUAL AWARENESS Definition: Construct and maintain current representations of the posture of organizational missions or business functions while considering threat events and courses of action. | Support situational awareness. Enhance understanding of dependencies among cyber and non-cyber resources. Reveal patterns or trends in adversary behavior. |
| COORDINATED PROTECTION Definition: Ensure that protection mechanisms operate in a coordinated and effective manner. | Require an adversary to overcome multiple safeguards (i.e., implement a strategy of defense-in-depth). Increase the difficulty for an adversary to successfully attack critical resources, increasing the cost to the adversary and raising the likelihood of adversary detection. Ensure that the use of any given protection mechanism does not create adverse, unintended consequences by interfering with other protection mechanisms. Validate the realism of cyber courses of action. |
| DECEPTION Definition: Mislead, confuse, hide critical assets from, or expose covertly tainted assets to the adversary. | Mislead, confuse, or hide critical assets from the adversary, thereby making the adversary uncertain of how to proceed, delaying the effect of the attack, increasing the risk of being discovered, causing the adversary to misdirect or waste its resources, and exposing the adversary tradecraft prematurely. |
| DIVERSITY Definition: Use heterogeneity to minimize common mode failures, particularly threat events exploiting common vulnerabilities. | Limit the possibility of the loss of critical functions due to the failure of replicated common components. Cause an adversary to expend more effort by developing malware or other TTPs appropriate for multiple targets; increase the probability that the adversary will waste or expose TTPs by applying them to targets for which they are inappropriate; and maximize the probability that some of the defending organization's systems will survive the adversary's attack. |
| DYNAMIC POSITIONING Definition: Distribute and dynamically relocate functionality or system resources. | Increase the ability to rapidly recover from non-adversarial events (e.g., fires, floods) as well as from cyber attacks. Impede an adversary's ability to locate, eliminate, or corrupt mission or business assets, and cause the adversary to spend more time and effort finding the organization's critical assets, thereby increasing the probability of the adversary revealing their presence, actions, and tradecraft prematurely. |
| NON-PERSISTENCE Definition: Generate and retain resources as needed or for a limited time. | Reduce exposure to corruption, modification, or compromise. Provide a means of curtailing an adversary's intrusion and advance and potentially removing malware or damaged resources from the system. Limit the availability of resources the adversary could target. |
| PRIVILEGE RESTRICTION Definition: Restrict privileges based on the attributes of users and system elements as well as on environmental factors. | Limit the impact and probability that unintended actions by authorized individuals will compromise information or services. Impede an adversary by requiring them to invest more time and effort in obtaining credentials. Curtail the adversary's ability to take full advantage of credentials that they have obtained. |
| REALIGNMENT Definition: Structure systems and resource uses to meet mission or business function needs, reduce current and anticipated risks, and accommodate the evolution of technical, operational, and threat environments. | Minimize the connections between mission-critical and non-critical services, thus reducing the likelihood that a failure of non-critical services will impact mission-critical services. Reduce the attack surface of the defending organization by minimizing the probability that non-mission or business functions could be used as an attack vector. Accommodate changing mission or business function needs. Accommodate changes in the technical environment. |

| TECHNIQUE | PURPOSE |
|---|---|
| REDUNDANCY Definition: Provide multiple protected instances of critical resources. | Reduce the consequences of the loss of information or services. Facilitate recovery from the effects of an adverse cyber event. Limit the time during which critical services are denied or limited. |
| SEGMENTATION Definition: Define and separate system elements based on criticality and trustworthiness. | Contain adversary activities and non-adversarial stresses (e.g., fires, floods) to the enclave or segment in which they have established a presence. Limit the set of possible targets to which malware can be easily propagated. |
| SUBSTANTIATED INTEGRITY Definition: Ascertain whether critical system elements have been corrupted. | Facilitate the determination of correct results in case of conflicts between diverse services or inputs. Detect attempts by an adversary to deliver compromised data, software, or hardware, as well as successful modification or fabrication. |
| UNPREDICTABILITY Definition: Make changes randomly or unpredictably. | Increase an adversary's uncertainty regarding the system protections that they may encounter, thus making it more difficult for them to ascertain the appropriate course of action. Serve as a force multiplier for other techniques. |

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TABLE D-3: POTENTIAL INTERACTIONS BETWEEN CYBER RESILIENCY TECHNIQUES

| Technique / Enabler B | Adaptive Response | Analytic Monitoring | Contextual Awareness | Coordinated Protection | Deception | Diversity | Dynamic Positioning | Non-Persistence | Privilege Restriction | Realignment | Redundancy | Segmentation | Substantiated Integrity | Unpredictability |
|-------------------------------|-------------------|---------------------|----------------------|------------------------|-----------|-----------|---------------------|-----------------|-----------------------|-------------|------------|--------------|-------------------------|------------------|
| Technique A | | | | | | | | | | | | | | |
| <u>ADAPTIVE RESPONSE</u> | - | D | U | S | | U | U/S | U/S | U/S | | U | U/S | U | U |
| <u>ANALYTIC MONITORING</u> | S | - | S | D | U | U | U | | | | | | U/S | |
| <u>CONTEXTUAL AWARENESS</u> | S | U | - | | | | | | | S | | | U | |
| <u>COORDINATED PROTECTION</u> | U | S | | - | | U | U | U | U/S | U | U | U | | |
| <u>DECEPTION</u> | | U/C | C/S | | - | | U | | | | | U | S | U |
| <u>DIVERSITY</u> | S | C/S | C | C/S | | - | S | | U | U | U/S | | U | S |
| <u>DYNAMIC POSITIONING</u> | U/S | C/S | | | S | U | - | U | | | U | | | U/S |
| <u>NON-PERSISTENCE</u> | U/S | C | C | | | | S | - | | S | | | U | S |
| <u>PRIVILEGE RESTRICTION</u> | S | | | U | | | | | - | S | | | U | |
| <u>REALIGNMENT</u> | C | | U | C/S | | C/S | | | S | - | C | | | |

| Technique / Enabler B | Adaptive Response | Analytic Monitoring | Contextual Awareness | Coordinated Protection | Deception | Diversity | Dynamic Positioning | Non-Persistence | Privilege Restriction | Realignment | Redundancy | Segmentation | Substantiated Integrity | Unpredictability |
|--------------------------------|-------------------|---------------------|----------------------|------------------------|-----------|-----------|---------------------|-----------------|-----------------------|-------------|------------|--------------|-------------------------|------------------|
| Technique A | | | | | | | | | | | | | | |
| <u>REDUNDANCY</u> | S | | | | | U | S | | | | - | | U | |
| <u>SEGMENTATION</u> | U/S | C | | S | S | | | | | | - | | | U |
| <u>SUBSTANTIATED INTEGRITY</u> | S | S/U | S | | U | S | | S | S | | S | | - | |
| <u>UNPREDICTABILITY</u> | C/S | C | | C | S | U | U/S | U | | | | | | - |

Key:

- **S** indicates that the technique in the row (Technique A) *supports* the one in the column (Technique B). Technique B is made more effective by Technique A.
- **D** indicates that Technique A *depends on* Technique or Enabler B. Technique A will be ineffective if not used in conjunction with Technique or Enabler B.
- **U** indicates that Technique A can *use* Technique or Enabler B. Technique A can be implemented effectively in the absence of Technique B. However, more options become available if Technique B is also used.
- **C** indicates that Technique A can *conflict with* or *complicate* Technique B. Some or all implementations of Technique A could undermine the effectiveness of Technique B.

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2192 D.4 CYBER RESILIENCY IMPLEMENTATION APPROACHES

2193 This section identifies representative cyber resiliency *approaches* to implementing cyber
 2194 resiliency techniques. A cyber resiliency approach is a subset of the technologies and processes
 2195 included in a cyber resiliency technique and is defined by how the capabilities are implemented
 2196 or how the intended consequences are achieved. [Table D-4](#) lists each cyber resiliency technique,
 2197 representative approaches that can be used to implement the technique, and representative
 2198 examples. Where possible, examples are drawn from discussions associated with the controls
 2199 and control enhancements in [\[SP 800-53\]](#), even when these controls or enhancements do not
 2200 directly support cyber resiliency as described in [Appendix F](#). However, [\[SP 800-53\]](#) does not
 2201 address all approaches or all aspects of any individual approach. Therefore, some examples are
 2202 drawn from system reliability and system resilience practices and technologies and/or from
 2203 emerging cyber resiliency technologies. The set of approaches for a specific technique is not
 2204 exhaustive and represents relatively mature technologies and practices. Thus, technologies
 2205 emerging from research can be characterized in terms of the techniques they apply while not
 2206 being covered by any of the representative approaches.

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TABLE D-4: CYBER RESILIENCY APPROACHES

| TECHNIQUES | APPROACHES | EXAMPLES |
|--|---|---|
| ADAPTIVE RESPONSE Definition: Implement agile courses of action to manage risks. Discussion: Inform courses of action with situational awareness and predictive analytics for increased agility. All approaches can leverage virtualization and are compatible with zero trust architecture (ZTA) and cloud computing strategies. However, all approaches can also be applied to processes and reporting within a Security Operations Center (SOC). | DYNAMIC RECONFIGURATION Definition: Make changes to individual systems, system elements, components, or sets of resources to change functionality or behavior without interrupting service. Informal description: Change how resources are or can be used. Discussion: Reconfiguration needs to be executed without significantly degrading or interrupting service. | <ul style="list-style-type: none"> Dynamically change router rules, access control lists, intrusion detection and prevention system parameters, and filter rules for firewalls and gateways. Reassign responsibilities among staff within a security operations center (SOC) based on expertise with a technology for which new warnings have been shared. |
| | DYNAMIC RESOURCE ALLOCATION Definition: Change the allocation of resources to tasks or functions without terminating critical functions or processes. Informal description: Change how much of a resource can be used. Discussion: Reallocate resources to tasks or functions without terminating critical functions or processes. | <ul style="list-style-type: none"> Employ dynamic provisioning. Reprioritize messages or services. Implement load-balancing. Provide emergency shutoff capabilities. Preempt communications. Instruct SOC staff to prioritize analysis and response to one incident among multiple suspected incidents. |
| | ADAPTIVE MANAGEMENT Definition: Change how mechanisms are used based on changes in the operational environment as well as changes in the threat environment. Informal description: Change in response to change. Discussion: Manage how mechanisms can be used based on changes in the operational environment as well as changes in the threat environment. | <ul style="list-style-type: none"> Disable access dynamically. Implement adaptive authentication. Provide for the automatic disabling of a system or service. Provide dynamic deployment of new or replacement resources or capabilities. Use automated decision-making supported by artificial intelligence (AI) or machine learning (ML) for rapid response and dynamic changes when human operators are not available. Create a temporary incident-focused team reporting structure within an SOC. |
| ANALYTIC MONITORING Definition: Monitor and analyze a wide range of properties and behaviors on an ongoing basis and in a coordinated way. Discussion: Systems can accumulate vast amounts of monitoring or logging data. Use monitoring data | MONITORING AND DAMAGE ASSESSMENT Definition: Monitor and analyze behavior and characteristics of components and resources to look for indicators of adversary activity or precursor conditions or indications of other threat events and to detect and assess damage from adversity. Informal description: Look for indications that something might be | <ul style="list-style-type: none"> Use hardware fault detection. Employ Continuous Diagnostics and Mitigation (CDM) or other vulnerability scanning tools. Deploy intrusion detection systems (IDSs) and other monitoring tools. Use insider threat monitoring tools. Perform telemetry analysis. Detect malware beaconing. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| strategically to inform defensive activities. | <p>awry and what damage might have occurred.</p> <p>Discussion: Leverage Continuous Diagnostics and Mitigation (CDM) and other monitoring capabilities, including those related to health and status (H&S). Integrate with threat hunting and insider threat monitoring.</p> | <ul style="list-style-type: none"> Monitor open-source information for indicators of disclosure or compromise. |
| | <p>SENSOR FUSION AND ANALYSIS</p> <p>Definition: Fuse and analyze monitoring data and analysis results from different information sources or at different times together with externally provided threat intelligence.</p> <p>Informal description: Put the pieces together from many different sources.</p> <p>Discussion: Consider all possible sources of monitoring information, including CDM, H&S, physical access logs, and insider threat monitoring.</p> | <ul style="list-style-type: none"> Enable organization-wide situational awareness. Implement cross-organizational auditing. Correlate data from different tools. Fuse data from physical access control systems and information systems. |
| | <p>FORENSIC AND BEHAVIORAL ANALYSIS</p> <p>Definition: Analyze adversary TTPs, including observed behavior, malware, and other artifacts left behind by adverse events.</p> <p>Informal description: Analyze adversary activities and artifacts.</p> <p>Discussion: Ensure that policies and practices are in place to capture evidence and support analysis.</p> | <ul style="list-style-type: none"> Deploy an integrated team of forensic and malware analysts, developers, and operations personnel. Use reverse engineering and other malware analysis tools. |
| <p>CONTEXTUAL AWARENESS</p> <p>Definition: Construct and maintain current representations of the posture of missions or business functions while considering threat events and courses of action.</p> <p>Discussion: Maintain cyber situational awareness to support mission continuity.</p> | <p>DYNAMIC RESOURCE AWARENESS</p> <p>Definition: Maintain current information about resources, the status of resources, and resource connectivity.</p> <p>Informal description: Maintain awareness of systems' performance and security posture.</p> <p>Discussion: Integrate network performance, system performance, and continuous diagnostics as part of situational awareness.</p> | <ul style="list-style-type: none"> Maintain a real-time network map. Integrate health and status (H&S) data with outputs of CDM tools. |
| | <p>DYNAMIC THREAT AWARENESS</p> <p>Definition: Maintain current information about threat actors, indicators, and potential, predicted, and observed adverse events.</p> | <ul style="list-style-type: none"> Track predicted or impending natural disasters. Dynamically ingest incident and threat data. Track ownership changes of suppliers and other depended-on parties. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>Informal description: Maintain a current awareness of threats that are both observed and anticipated.</p> <p>Discussion: Ensure that the organization's security operations center (SOC) ingests cyber threat intelligence.</p> <p>MISSION DEPENDENCY AND STATUS VISUALIZATION</p> <p>Definition: Maintain current information about the status of missions or business functions, dependencies on resources, and the status of those resources with respect to threats.</p> <p>Informal description: Maintain an up-to-date cyber operational picture.</p> <p>Discussion: Maintain an up-to-date dependency map for mission-essential or business-essential functions. Integrate resource and threat awareness into situational awareness, and enable focused visualization for high-value assets and infrastructure services.</p> | <ul style="list-style-type: none"> Facilitate integrated situational awareness of threats. Maintain a mission-wide or organization-wide operational picture or dashboard. Maintain a current security posture assessment for critical resources or high-value assets. |
| <p>COORDINATED PROTECTION</p> <p>Definition: Ensure that protection mechanisms operate in a coordinated and effective manner.</p> <p>Discussion: Lack of coordination introduces fragility and creates exposures to threats.</p> | <p>CALIBRATED DEFENSE-IN-DEPTH</p> <p>Definition: Provide complementary protective mechanisms at different architectural layers or in different locations, calibrating the strength and number of mechanisms to resource value.</p> <p>Informal description: Do not expect one defense to suffice. Apply layered defenses based on risk.</p> <p>Discussion: Avoid creating single points of failure.</p> | <ul style="list-style-type: none"> Design for defense-in-depth. Employ multiple, distinct authentication challenges over the course of a session to confirm identity. Combine network and host-based intrusion detection. Provide increasing levels of protection to access more sensitive or critical resources. Conduct sensitivity and criticality analyses. |
| | <p>CONSISTENCY ANALYSIS</p> <p>Definition: Determine whether and how protections can be applied in a coordinated, consistent way that minimizes interference, potential cascading failures, or coverage gaps.</p> <p>Informal description: Minimize opportunities for the system's security capabilities to be used incompletely or inconsistently.</p> <p>Discussion: Over time, changing access policies for information, allowable uses of capabilities, and dependencies among systems and</p> | <ul style="list-style-type: none"> Employ unified Identity, Credential, and Access Management (ICAM) administration tools. Analyze mission and business process flows and threads. Employ privilege analysis tools to support an ongoing review of whether user privileges are assigned consistently. Interpret attributes consistently. Use machine learning for access control policy verification [IR 8360]. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>components can produce fragility and provide adversaries with opportunities.</p> <p>ORCHESTRATION Definition: Coordinate modifications to and the ongoing behavior of mechanisms and processes at different layers, in different locations, or implemented for different aspects of trustworthiness to avoid causing cascading failures, interference, or coverage gaps. Informal description: Coordinate security capabilities at different layers and in different systems or system components to avoid coverage gaps or interference. Discussion: Orchestrate updates of capabilities and policies, particularly, for identity, credentialing, and access management (ICAM) across systems. Orchestrate monitoring across architectural layers. Use a cyber playbook to orchestrate incident response efforts.</p> | <ul style="list-style-type: none"> Design for facilitating coordination and mutual support among safeguards. Coordinate incident handling with mission and business process continuity of operations and organizational processes. Coordinate the planning, training, and testing of incident response, contingency planning, etc. Make software updates in a consistent, coordinated way across the organization. Deploy ICAM policy updates in a consistent, coordinated way across the organization. Conduct coverage planning and management for sensors. Use cyber playbooks. |
| | <p>SELF-CHALLENGE Definition: Affect mission or business processes or system elements adversely in a controlled manner to validate the effectiveness of protections and enable proactive response and improvement. Informal description: Validate the effectiveness of capabilities and processes in action. Discussion: Use tabletop exercises (TTXs), Red Teams, penetration testing, or automated fault injection throughout the system life cycle and with different scopes.</p> | <ul style="list-style-type: none"> Hardware power-on self-test. Conduct role-based training exercises. Conduct penetration testing and Red Team exercises. Test automated incident response. Employ fault injection. Conduct tabletop exercises. |
| <p>DECEPTION Definition: Mislead, confuse, hide critical assets from, or expose covertly tainted assets to the adversary. Discussion: Apply deception strategically, tactically, or both. Ensure that cyber risk governance and SOC operations allow for</p> | <p>OBFUSCATION Definition: Hide, transform, or otherwise obscure the contents, properties, or presence of information or other assets from the adversary. Informal description: Make information difficult for the adversary to find and understand. Discussion: Encryption is a key method for obfuscation.</p> | <ul style="list-style-type: none"> Encrypt data at rest. Use steganographic encoding (e.g., digital watermarking). Encrypt transmitted data (e.g., using a Virtual Private Network [VPN]). Encrypt authenticators. Randomize communications patterns. Conceal the presence of system components on an internal network. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| deception, and maintain deception resources. | | <ul style="list-style-type: none"> • Mask, encrypt, hash, or replace identifiers. • Obfuscate traffic via onion routing. • Apply chaffing to communications traffic. • Add a large amount of valid but useless information to a data store. • Perform encrypted processing. |
| | <p>DISINFORMATION</p> <p>Definition: Provide deliberately misleading information to adversaries.</p> <p>Informal description: Deceive adversaries.</p> <p>Discussion: Typical forms of disinformation include decoy accounts and decoy credentials.</p> | <ul style="list-style-type: none"> • Post questions to a public forum based on false information about the system. • Create false (“canary”) credentials and tokens (e.g., honeytokens). |
| | <p>MISDIRECTION</p> <p>Definition: Maintain deception resources or environments, and direct adversary activities there.</p> <p>Informal description: Direct adversary activities to deception environments or resources.</p> <p>Discussion: Commercial products can be used to create and maintain a deception network, but ongoing effort is needed to keep it current, engage with adversaries, and analyze adversary TTPs.</p> | <ul style="list-style-type: none"> • Establish and maintain honeypots, honeynets, or decoy files. • Maintain a full-scale, all-encompassing deception environment. |
| | <p>TAINTING</p> <p>Definition: Embed covert capabilities in resources.</p> <p>Informal description: Cause what adversaries steal to identify them or otherwise harm them.</p> <p>Discussion: Enable exfiltrated data to “phone home.”</p> | <ul style="list-style-type: none"> • Use beacon traps. • Employ internal network table cache poisoning (e.g., Domain Name System [DNS], Address Resolution Protocol [ARP]). • Include false entries or steganographic data in files to enable them to be found via open-source analysis. |
| <p>DIVERSITY</p> <p>Definition: Use heterogeneity to minimize common mode failures, particularly threat events that exploit common vulnerabilities.</p> <p>Discussion: Enterprise systems often include some incidental diversity as a result of procurements by different programs or at different</p> | <p>ARCHITECTURAL DIVERSITY</p> <p>Definition: Use multiple sets of technical standards, different technologies, and different architectural patterns.</p> <p>Informal description: Use different technical architectures.</p> <p>Discussion: An organization can use, for example, both Windows and Linux. An organization’s cloud</p> | <ul style="list-style-type: none"> • Use auditing/logging systems on different OSs to acquire and store audit/logging data. • Apply different audit/logging regimes at different architectural layers. • Deploy diverse operating systems. • Support multiple protocol standards. • [Non-cyber example] Use both airplanes and lighter-than-air aircraft for air transportation. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| <p>times. Poorly managed, this can be costly and create security risks; well managed, it can make an adversary's job harder. Due to reliance on common libraries and infrastructures, diversity can be more apparent than real. Therefore, analysis is needed to verify the extent of diversity.</p> | <p>strategy can involve multiple cloud infrastructures.</p> <p>DESIGN DIVERSITY</p> <p>Definition: Use different designs within a given architecture to meet the same requirements or provide equivalent functionality.</p> <p>Informal description: Provide multiple ways to meet requirements.</p> <p>Discussion: Within the context of a given architecture, parallel design teams can solve the same problem in different ways, thus producing different attack surfaces.</p> | <ul style="list-style-type: none"> • Employ N-version programming. • Employ mixed-signal design diversity (using both analog and digital signals). • Employ mixed-level design diversity (using both hardware and software implementations). • [Non-cyber example] Use both helium-filled and hot air dirigibles. |
| | <p>SYNTHETIC DIVERSITY</p> <p>Definition: Transform implementations of software to produce a variety of instances.</p> <p>Informal description: Use automation to tweak software implementations.</p> <p>Discussion: Synthetic diversity can be applied to IoT devices.</p> | <ul style="list-style-type: none"> • Implement address space layout randomization. • Use randomizing compilers. |
| | <p>INFORMATION DIVERSITY</p> <p>Definition: Provide information from different sources or transform information in different ways.</p> <p>Informal description: Use multiple sources for the same information.</p> <p>Discussion: Use of information from different sources can reveal adversary injection or modification.</p> | <ul style="list-style-type: none"> • Apply different analog-to-digital conversion methods to non-digitally-obtained data. • Use multiple data sources. |
| | <p>PATH DIVERSITY</p> <p>Definition: Provide multiple independent paths for command, control, and communications.</p> <p>Informal description: Do not rely on a single mode of communication.</p> <p>Discussion: In particular, ensure alternative lines of communications for incident response and continuity of an organization's essential functions.</p> | <ul style="list-style-type: none"> • Establish alternate telecommunications services (e.g., ground-based circuits, satellite communications). • Employ alternate communications protocols. • Use out-of-band channels. |
| | <p>SUPPLY CHAIN DIVERSITY</p> <p>Definition: Use multiple independent supply chains for critical components.</p> <p>Informal description: Look for ways to avoid relying on a single supply chain.</p> | <ul style="list-style-type: none"> • Use a diverse set of suppliers. • Analyze components from different suppliers to determine whether they contain common elements (e.g., included software libraries). |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>Discussion: Determine when and how to use supply chain diversity as part of the organization's SCRM strategy.</p> | |
| DYNAMIC POSITIONING <p>Definition: Distribute and dynamically relocate functionality or system resources.</p> <p>Discussion: Use moving target defenses to make an adversary's job harder.</p> | <p>FUNCTIONAL RELOCATION OF SENSORS</p> <p>Definition: Relocate sensors or reallocate responsibility for specific sensing tasks to look for indicators of adverse events.</p> <p>Informal description: Keep your eyes moving.</p> <p>Discussion: Relocating sensors compensates for blind spots and makes it harder for an adversary to hide.</p> | <ul style="list-style-type: none"> • Relocate (using virtualization) or reconfigure IDSs or IDS sensors. |
| | <p>FUNCTIONAL RELOCATION OF CYBER RESOURCES</p> <p>Definition: Change the location of cyber resources that provide functionality or information, either by moving the assets or by transferring functional responsibility.</p> <p>Informal description: Keep your cyber resources moving.</p> <p>Discussion: Make the adversary's discovery and network mapping efforts go stale quickly.</p> | <ul style="list-style-type: none"> • Change processing locations (e.g., switch to a virtual machine on a different physical component). • Change storage sites (e.g., switch to an alternate data store on a different storage area network). |
| | <p>ASSET MOBILITY</p> <p>Definition: Securely move physical resources.</p> <p>Informal description: Do not confine physical resources to one location.</p> <p>Discussion: This approach is applicable to cyber-physical and tactical systems.</p> | <ul style="list-style-type: none"> • Move a mobile device or system component (e.g., a router) from one room in a facility to another while monitoring its movement. • Move storage media securely from one room or facility to another room or facility. • Move a platform or vehicle to avoid collision or other physical harm while retaining knowledge of its location. |
| | <p>FRAGMENTATION</p> <p>Definition: Partition information and distribute it across multiple components.</p> <p>Informal description: Create an information jigsaw puzzle.</p> <p>Discussion: Manage fragmented data to ensure its ongoing quality, minimize its exposure, and minimize performance inefficiencies.</p> | <ul style="list-style-type: none"> • Strategically implement data fragmentation and partitioning to maintain performance while ensuring quality. |
| | <p>DISTRIBUTED FUNCTIONALITY</p> <p>Definition: Decompose a function or application into smaller functions, and</p> | <ul style="list-style-type: none"> • Architect applications so that constituent functions can be located on different system components. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>distribute those functions across multiple components.</p> <p>Informal description: Use fine-grained control of resource use.</p> <p>Discussion: Distributed functionality can be used with micro-segmentation and ZTA.</p> | |
| NON-PERSISTENCE Definition: Generate and retain resources as needed or for a limited time. Discussion: Reduce the attack surface in the temporal dimension, and reduce costs with just-in-time provisioning. | <p>NON-PERSISTENT INFORMATION Definition: Refresh information periodically, or generate information on demand and delete it when no longer needed. Informal description: Limit how long information is exposed. Discussion: Determine how temporary “temporary” files are.</p> <p>NON-PERSISTENT SERVICES Definition: Refresh services periodically, or generate services on demand and terminate services when no longer needed. Informal description: Do not allow a service to run indefinitely. It may have been compromised while executing. Discussion: Instantiating services on demand and expunging them when inactive can be a performance management strategy as well.</p> <p>NON-PERSISTENT CONNECTIVITY Definition: Establish connections on demand, and terminate connections when no longer needed. Informal description: Do not leave a communications line open. Discussion: Leverage software-defined networking (SDN), particularly in a ZTA.</p> | <ul style="list-style-type: none"> Delete high-value mission information after it is processed. Offload audit records to offline storage. Use one-time passwords or nonces. <ul style="list-style-type: none"> Employ time-based or inactivity-based session termination. Reimage components. Refresh services using virtualization. <ul style="list-style-type: none"> Implement software-defined networking. Employ time-based or inactivity-based network disconnection. |
| PRIVILEGE RESTRICTION Definition: Restrict privileges based on attributes of users and system elements as well as on environmental factors. Discussion: Apply existing capabilities more stringently, and integrate ZT technologies. | <p>TRUST-BASED PRIVILEGE MANAGEMENT Definition: Define, assign, and maintain privileges based on established trust criteria consistent with the principles of least privilege. Informal description: Trust no more than necessary. Discussion: Separate roles and responsibilities, and use dual authorization.</p> <p>ATTRIBUTE-BASED USAGE RESTRICTION</p> | <ul style="list-style-type: none"> Implement least privilege. Employ location-based account restrictions. Employ time-based restrictions on automated processes. Require dual authorization for critical actions. <ul style="list-style-type: none"> Employ role-based access control (RBAC). |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>Definition: Define, assign, maintain, and apply usage restrictions on cyber resources based on the criticality of missions or business functions and other attributes (e.g., data sensitivity).</p> <p>Informal description: Restrict use narrowly.</p> <p>Discussion: Avoid treating a system or an application as a Swiss Army knife.</p> | <ul style="list-style-type: none"> Employ attribute-based access control (ABAC). Restrict the use of maintenance tools. Apply asset tag policy restrictions to the use of cloud services. Use dynamic data masking. |
| | <p>DYNAMIC PRIVILEGES</p> <p>Definition: Elevate or decrease privileges assigned to a user, process, or service based on transient or contextual factors.</p> <p>Informal description: Make privileges context-sensitive.</p> <p>Discussion: Make access and usage decisions based on the current state and recent history.</p> | <ul style="list-style-type: none"> Implement time-based adjustments to privileges due to the status of mission or business tasks. Employ dynamic account provisioning. Disable privileges based on a determination that an individual or process is high-risk. Implement dynamic revocation of access authorizations. Implement dynamic association of attributes with cyber resources and active entities. Implement dynamic credential binding. |
| <p>REALIGNMENT</p> <p>Definition: Structure systems and resource uses to meet mission or business function needs, reduce current and anticipated risks, and accommodate the evolution of the technical, operational, and threat environments.</p> <p>Discussion: Look for restructuring opportunities related to new systems and programs, as well as planned upgrades to existing systems.</p> | <p>PURPOSING</p> <p>Definition: Ensure that cyber resources are used consistently with mission or business function purposes and approved uses, thereby avoiding unnecessary sharing and complexity.</p> <p>Informal description: Ensure that resources are used consistently with mission or business function purposes and approved uses.</p> <p>Discussion: Avoid “mission creep,” which can increase a system’s attack surface.</p> | <ul style="list-style-type: none"> Use allow-listing to prevent the installation of unapproved applications, such as games or peer-to-peer music sharing. Use allow-listing to restrict communications to a specified set of addresses. Ensure that privileged accounts are not used for non-privileged functions. Ensure that no resource is designated as trusted unless a mission or business reason justifies that designation. |
| | <p>OFFLOADING</p> <p>Definition: Offload supportive but nonessential functions to other systems or to an external provider that is better able to perform the functions securely.</p> <p>Informal description: Offload functions when an external provider can do a better job.</p> <p>Discussion: Offloading reduces the attack surface and motivates ongoing consideration of what is essential.</p> | <ul style="list-style-type: none"> Outsource nonessential services to a managed service provider. Impose requirements on and perform oversight of external system services. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| | <p>RESTRICTION</p> <p>Definition: Remove or disable unneeded functionality or connectivity, or add mechanisms to reduce the chance of vulnerability or failure.</p> <p>Informal description: Lock capabilities down.</p> <p>Discussion: Lock capabilities down even though that reduces agility and leaves some capabilities unused.</p> | <ul style="list-style-type: none"> Configure the system to provide only essential capabilities. Minimize non-security functionality. |
| | <p>REPLACEMENT</p> <p>Definition: Replace low-assurance or poorly understood implementations with trustworthy implementations.</p> <p>Informal description: Replace those components that cannot be trusted.</p> <p>Discussion: In certain circumstances, it is best to discard components, particularly in light of supply chain risks. However, the decommissioning and replacement processes need to be secure.</p> | <ul style="list-style-type: none"> Remove or replace unsupported system components to reduce risk. |
| | <p>SPECIALIZATION</p> <p>Definition: Uniquely augment, configure, or modify the design of critical cyber resources for missions or business functions to improve trustworthiness.</p> <p>Informal description: Build special-purpose components or develop non-standard implementations.</p> <p>Discussion: Prevent the adversary from being able to mirror your system.</p> | <ul style="list-style-type: none"> Reimplement or custom develop critical components. Develop custom system elements covertly. Define and apply customized configurations. |
| | <p>EVOLVABILITY</p> <p>Definition: Provide mechanisms and structure resources to enable the system to be maintained, modified, extended, or used in new ways without increasing security or mission risk.</p> <p>Informal description: Do not commit to a static architecture or an architecture that is difficult to change.</p> <p>Discussion: Expect a broader range of “plug and play” capabilities over time.</p> | <ul style="list-style-type: none"> Use function, driver, and object wrappers to facilitate the rapid removal and replacement of components. Use microservices to support incremental changes. Use virtualization to enable new or different applications and OSs to be installed rapidly. Integrate ongoing training into mission or business processes to accommodate change. |
| REDUNDANCY | <p>PROTECTED BACKUP AND RESTORE</p> <p>Definition: Back up information and software (including configuration data</p> | <ul style="list-style-type: none"> Retain previous baseline configurations. |

| TECHNIQUES | APPROACHES | EXAMPLES |
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| <p>Definition: Provide multiple protected instances of critical resources.</p> <p>Discussion: Redundancy is integral to system resilience, but it must be carefully managed to avoid redundant vulnerabilities and an increased attack surface.</p> | <p>and virtualized resources) in a way that protects its confidentiality, integrity, and authenticity. Enable safe and secure restoration in case of disruption or corruption.</p> <p>Informal description: Back up resources securely and defend the restore process from adversary exploitation.</p> <p>Discussion: Keep in mind that transitions are often periods of exposure, and backups can be compromised.</p> | <ul style="list-style-type: none"> Maintain and protect system-level backup information (e.g., operating system, application software, system configuration data). Increase monitoring and analysis during restore operations. |
| | <p>SURPLUS CAPACITY</p> <p>Definition: Maintain extra capacity for information storage, processing, or communications.</p> <p>Informal description: Do not economize on resources; provide surge capacity.</p> <p>Discussion: Where possible, use diverse resources to provide surplus capacity.</p> | <ul style="list-style-type: none"> Maintain spare parts (i.e., system components). Address surplus capacity in service-level agreements with external systems. |
| | <p>REPLICATION</p> <p>Definition: Duplicate hardware, information, backups, or functionality in multiple locations, and keep them synchronized.</p> <p>Informal description: Replicate capabilities in multiple locations, and keep them synchronized.</p> <p>Discussion: Where possible, replicate capabilities using diverse resources.</p> | <ul style="list-style-type: none"> Provide an alternate audit capability. Create a shadow database. Maintain one or more alternate storage sites. Maintain one or more alternate processing sites. Maintain a redundant secondary system. Provide alternative security mechanisms. Implement a redundant name and address resolution service. |
| <p>SEGMENTATION</p> <p>Definition: Define and separate system elements based on criticality and trustworthiness.</p> <p>Discussion: Reduce the adversary's scope for lateral movement or command and control (C2).</p> | <p>PREDEFINED SEGMENTATION</p> <p>Definition: Define enclaves, segments, micro-segments, or other restricted types of resource sets based on criticality and trustworthiness so that they can be protected separately and, if necessary, isolated.</p> <p>Informal description: Define enclaves, segments, or micro-segments to protect them separately.</p> <p>Discussion: Predefined enclaves and micro-segmentation facilitate the risk-calibrated use of other security and cyber resiliency techniques.</p> | <ul style="list-style-type: none"> Use virtualization to maintain separate processing domains based on user privileges. Use cryptographic separation for maintenance. Partition applications from system functionality. Isolate security functions from non-security functions. Use physical separation (air gap) to isolate security tools and capabilities. Isolate components based on organizational missions or business functions. |

| TECHNIQUES | APPROACHES | EXAMPLES |
|---|---|--|
| | | <ul style="list-style-type: none"> Separate subnets that connect to different security domains. In particular, provide a DMZ for Internet connectivity. Use cross-domain solutions to separate security domains. Employ system partitioning. Implement micro-segmentation using software agents. Employ process isolation. Implement sandboxes and other confined environments. Implement memory protection. |
| | <p>DYNAMIC SEGMENTATION AND ISOLATION</p> <p>Definition: Change the configuration of enclaves or protected segments, or isolate resources while minimizing operational disruption.</p> <p>Informal description: Isolate resources dynamically to reduce transient risks.</p> <p>Discussion: The use of dynamic segmentation and isolation, consistent with ZT principles, can be particularly useful for high-value assets.</p> | <ul style="list-style-type: none"> Implement dynamic isolation of components. Implement software-defined networking (SDN), network function virtualization (NFV), and VPNs to define new enclaves. Create a virtualized sandbox or detonation chamber for untrusted attachments or URLs. |
| <p>SUBSTANTIATED INTEGRITY</p> <p>Definition: Ascertain whether critical system elements have been corrupted.</p> <p>Discussion: Verify that critical system elements can be trusted and have not been subjected to tampering or other malicious activity.</p> | <p>INTEGRITY CHECKS</p> <p>Definition: Apply and validate checks of the integrity or quality of information, components, or services to guard against surreptitious modification.</p> <p>Informal description: Check for modifications to data and software.</p> <p>Discussion: Integrity checks can be applied to information, metadata, components, or services.</p> | <ul style="list-style-type: none"> Use tamper-evident seals and anti-tamper coatings. Use automated tools for data quality checking. Use blockchain technology. Use non-modifiable executables. Use polling techniques to identify potential damage. Implement cryptographic hashes to address the modification of checksums as well as data. Validate the trustworthiness of a cloud server platform before launching a container worker node and periodically during container runtime execution. Employ information input validation. Validate components as part of SCRM. Employ integrity checking on external systems. |

| TECHNIQUES | APPROACHES | EXAMPLES |
|---|--|--|
| | <p>PROVENANCE TRACKING</p> <p>Definition: Identify and track the provenance of data, software, or hardware elements.</p> <p>Informal description: Verify the source of the system elements on which the organization depends.</p> <p>Discussion: Make provenance tracking part of SCRM.</p> | <ul style="list-style-type: none"> • Employ component traceability as part of SCRM. • Employ provenance tracking as part of SCRM. • Implement anti-counterfeit protections. • Implement a trusted path. • Implement code signing. |
| | <p>BEHAVIOR VALIDATION</p> <p>Definition: Validate the behavior of a system, service, device, or individual user against defined or emergent criteria (e.g., requirements, patterns of prior usage).</p> <p>Informal description: Validate behavior against defined or emergent criteria.</p> <p>Discussion: Learn what activities or behaviors are normal and what activities or behaviors are suspicious. Coordinate with insider threat mitigation.</p> | <ul style="list-style-type: none"> • Employ detonation chambers. • Implement function verification. • Verify boot process integrity. • Implement fault injection to observe potential anomalies in error handling. |
| <p>UNPREDICTABILITY</p> <p>Definition: Make changes randomly or unpredictably.</p> <p>Discussion: Maintain an environment of uncertainty for the adversary. Keep the adversary guessing.</p> | <p>TEMPORAL UNPREDICTABILITY</p> <p>Definition: Change behavior or state at times that are determined randomly or by complex functions.</p> <p>Informal description: Keep the adversary from extrapolating from past events.</p> <p>Discussion: Do not let the present conditions or circumstances duplicate the past.</p> <p>CONTEXTUAL UNPREDICTABILITY</p> <p>Definition: Change behavior or state in ways that are determined randomly or by complex functions.</p> <p>Informal description: Keep the adversary from extrapolating from similar events.</p> <p>Discussion: Do not let the adversary take advantage of consistency.</p> | <ul style="list-style-type: none"> • Require reauthentication at random intervals. • Perform routine actions at different times of the day. <ul style="list-style-type: none"> • Rotate roles and responsibilities. • Implement random channel-hopping. • Use random masking in dynamic data masking. |

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2210 As the examples in [Table D-4](#) illustrate, cyber resiliency techniques and approaches can be applied at a variety of architectural layers or system elements, including elements of the technical system (e.g., hardware, networking, software, and information stores) and system elements that are part of the larger socio-technical system: operations (e.g., people and

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2214 processes supporting cyber defense, system administration, and mission or business function
 2215 tasks), support (e.g., programmatic, systems engineering, maintenance and support), and
 2216 environment of operation (e.g., physical access restrictions and physical location). For a
 2217 representative set of architectural layers, [Table D-5](#) indicates approaches that could be applied
 2218 at those layers. In [Table D-5](#), “other software” includes specialized software intended to
 2219 implement cyber resiliency or cybersecurity capabilities. Some approaches (e.g., [Calibrated](#)
 2220 [Defense-in-Depth](#), [Consistency Analysis](#)) can involve working across multiple layers or at
 2221 multiple locations.

2222 TABLE D-5: ARCHITECTURAL LAYERS AT WHICH CYBER RESILIENCY APPROACHES CAN BE USED

| TECHNIQUES | APPROACHES | SOCIO-TECHNICAL SYSTEM | | | | | | | | | | | | |
|------------------------|----------------------------------|------------------------|---|-------------------------------|---|----------------|---|------------------|---|------------------------------------|-----------------------------|--------------------------|--|--|
| | | TECHNICAL SYSTEM | | | | | | | | INFORMATION STORAGE MANAGEMENT | TECHNICAL SYSTEM AS A WHOLE | ENVIRONMENT OF OPERATION | | |
| | | HARDWARE AND FIRMWARE | | NETWORKING AND COMMUNICATIONS | | OTHER SOFTWARE | | OPERATING SYSTEM | | CLOUD, VIRTUALWARE, INFRASTRUCTURE | | | | |
| | | | | | | | | | | | | | | |
| ADAPTIVE RESPONSE | Dynamic Reconfiguration | X | X | | | X | | X | X | | X | X | | |
| | Dynamic Resource Allocation | | X | | X | | X | X | X | | X | | | |
| | Adaptive Management | | X | | X | | | X | | | X | | | |
| ANALYTIC MONITORING | Monitoring and Damage Assessment | | X | X | | | | | | | X | X | | |
| | Sensor Fusion and Analysis | | X | X | X | | | | | | X | X | | |
| | Forensic and Behavioral Analysis | | | X | | | | | | | X | X | | |
| COORDINATED PROTECTION | Calibrated Defense-in-Depth | | | | | | | | | | X | X | | |
| | Consistency Analysis | | | X | | | | | | | X | X | | |
| | Orchestration | | | | | | X | | | | X | X | | |
| | Self-Challenge | X | X | X | X | | | X | | | X | | | |

| TECHNIQUES | APPROACHES | SOCIO-TECHNICAL SYSTEM | | | | | | | | | | | |
|----------------------|---|------------------------|-------------------------------|----------------|------------------|--|---|---|---|--------------------------------|-----------------------------|--|--|
| | | TECHNICAL SYSTEM | | | | | | | | INFORMATION STORAGE MANAGEMENT | TECHNICAL SYSTEM AS A WHOLE | | |
| | | SOFTWARE | | | | APPLICATION | | | | | | | |
| | | HARDWARE AND FIRMWARE | NETWORKING AND COMMUNICATIONS | OTHER SOFTWARE | OPERATING SYSTEM | CLOUD, VIRTUALIZATION MIDDLEWARE, INFRASTRUCTURE | | | | | | | |
| CONTEXTUAL AWARENESS | Dynamic Resource Awareness | | X | X | | | | | | X | X | | |
| | Dynamic Threat Awareness | | | X | | | | | | X | X | | |
| | Mission Dependency and Status Visualization | | | X | | | | | | X | X | | |
| DECEPTION | Obfuscation | X | X | X | X | | | X | X | | X X | | |
| | Disinformation | | | | | | | X | X | | X X | | |
| | Misdirection | | X | X | | | | | | X | X X | | |
| | Tainting | | X | X | | | X | | | | | | |
| DIVERSITY | Architectural Diversity | X | X | X | X | X | X | | | | | | |
| | Design Diversity | X | X | X | X | X | X | | | | | | |
| | Synthetic Diversity | | | | X | X | X | | | | | | |
| | Information Diversity | | | | | | | X | | X | | | |
| | Path Diversity | | X | | | | | | | | X | | |
| | Supply Chain Diversity | X | | | | | | | | | X | | |
| DYNAMIC POSITIONING | Functional Relocation of Sensors | | X | X | X | X | | | X | X | | | |
| | Functional Relocation of Cyber Resources | | X | X | X | X | | X | X | X | | | |
| | Asset Mobility | | | | | | | | | X | | | |
| | Fragmentation | | | | | | | X | | | | | |
| | Distributed Functionality | | | X | | X | X | | X | X | | | |

| TECHNIQUES | APPROACHES | SOCIO-TECHNICAL SYSTEM | | | | | | | | | | | |
|-----------------------|------------------------------------|------------------------|-------------------------------|----------------|------------------|--|---|---|---|--------------------------------|-----------------------------|--|--|
| | | TECHNICAL SYSTEM | | | | | | | | INFORMATION STORAGE MANAGEMENT | TECHNICAL SYSTEM AS A WHOLE | | |
| | | SOFTWARE | | | | APPLICATION | | | | | | | |
| | | HARDWARE AND FIRMWARE | NETWORKING AND COMMUNICATIONS | OTHER SOFTWARE | OPERATING SYSTEM | CLOUD, VIRTUALIZATION MIDDLEWARE, INFRASTRUCTURE | | | | | | | |
| NON-PERSISTENCE | Non-Persistent Information | | | | X | X | X | X | | X | | | |
| | Non-Persistent Services | | | | X | X | | | X | | | | |
| | Non-Persistent Connectivity | | X | | | | | | X | X | X | | |
| PRIVILEGE RESTRICTION | Trust-Based Privilege Management | | | X | X | | | X | | X | | | |
| | Attribute-Based Usage Restriction | X | X | X | X | | | X | | X | | | |
| | Dynamic Privileges | | | X | X | | | X | | X | | | |
| REALIGNMENT | Purposing | | X | X | X | | | X | | X | X | | |
| | Offloading | | | X | | | | X | | X | | | |
| | Restriction | | X | X | X | | | X | | X | X | | |
| | Replacement | X | | X | | | | | | | X | | |
| | Specialization | X | | X | | | | X | | | X | | |
| | Evolvability | | X | X | | X | X | | X | X | X | | |
| REDUNDANCY | Protected Backup and Restore | | | X | X | | | X | X | X | | | |
| | Surplus Capacity | X | X | | | X | X | X | | X | | | |
| | Replication | X | X | | | X | X | X | X | X | | | |
| SEGMENTATION | Predefined Segmentation | X | X | X | X | X | | X | | X | X | | |
| | Dynamic Segmentation and Isolation | X | X | X | X | X | | | | X | X | | |
| | Integrity Checks | X | X | X | X | X | X | X | | X | | | |

| TECHNIQUES | APPROACHES | SOCIO-TECHNICAL SYSTEM | | | | | | | | | | ENVIRONMENT OF OPERATION | | | | |
|-------------------------|-----------------------------|------------------------|-------------------------------|----------------|------------------|--|-------------|---|--|--------------------------------|-----------------------------|--------------------------|--|--|--|--|
| | | TECHNICAL SYSTEM | | | | | | | | INFORMATION STORAGE MANAGEMENT | TECHNICAL SYSTEM AS A WHOLE | | | | | |
| | | SOFTWARE | | | | OPERATIONS | SUPPORT | | | | | | | | | |
| | | HARDWARE AND FIRMWARE | NETWORKING AND COMMUNICATIONS | OTHER SOFTWARE | OPERATING SYSTEM | CLOUD, VIRTUALIZATION MIDDLEWARE, INFRASTRUCTURE | APPLICATION | | | | | | | | | |
| SUBSTANTIATED INTEGRITY | Provenance Tracking | X | X | | X | | X | X | | | X | | | | | |
| | Behavior Validation | X | X | X | X | X | X | | | X | | | | | | |
| UNPREDICTABILITY | Temporal Unpredictability | | X | X | X | X | X | | | X | | | | | | |
| | Contextual Unpredictability | | X | X | X | X | X | | | X | | | | | | |

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2225 D.5 CYBER RESILIENCY DESIGN PRINCIPLES

2226 This section provides a description of *strategic* and *structural* cyber resiliency design principles—
 2227 key constructs in the cyber resiliency engineering framework. It also describes relationships with
 2228 the design principles from other disciplines, the analytic practices necessary to implement the
 2229 principles, and how the application of the principles affects risk. In particular, relationships to
 2230 security design principles as described in [SP 800-160 v1] are identified.¹⁰⁸ As noted in [Section 2.1.4](#), strategic design principles express the organization’s risk management strategy, and
 2231 structural design principles support the strategic design principles.

2233 D.5.1 Strategic Design Principles

2234 Strategic cyber resiliency design principles guide and inform engineering analyses and risk
 2235 analyses throughout the system life cycle and highlight different structural design principles,
 2236 cyber resiliency techniques, and approaches to applying those techniques. [Table D-6](#) describes

¹⁰⁸ [SP 800-160 v1] defines security design principles in three broad categories: Security Architecture and Design, Security Capability and Intrinsic Behaviors, and Life Cycle Security. For a detailed discussion of relationships between security design principles and cyber resiliency techniques as well as cyber resiliency design principles, see [Bodeau17].

2237 five strategic cyber resiliency design principles and identifies the related design principles from
 2238 other disciplines.¹⁰⁹ ¹¹⁰

2239 TABLE D-6: STRATEGIC CYBER RESILIENCY DESIGN PRINCIPLES

| STRATEGIC DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|----------------------------------|---|--|
| FOCUS ON COMMON CRITICAL ASSETS. | <p>Motivation: Limited organizational and programmatic resources need to be applied where they can provide the greatest benefit. This results in a strategy of focusing first on assets that are both critical and common followed by those that are either critical or common.</p> <p>Guidance: Know which mission or business functions, tasks, capabilities, and assets are critical. Know which resources, assets, or services are essential to the successful performance of critical functions and tasks or to the protection of critical assets. Focus first on ensuring the security and cyber resiliency of those essential resources that are common across multiple functions as high-value adversary targets.</p> | <p>Security: Inverse Modification Threshold.</p> <p>Resilience Engineering: Physical Redundancy, Layered Defense, Loose Coupling.</p> <p>Survivability: Failure Mode Reduction, Fail-Safe, Evolution.</p> |

¹⁰⁹ Resilience Engineering design principles are described in the Systems Engineering Body of Knowledge [SEBoK] and [Jackson13]. Resilience Engineering design principles mapped to cyber resiliency design principles in this appendix are: Absorption (allow the system to withstand threats to a specified level), Human-in-the-Loop (allow the system to employ human elements when there is a need for human cognition), Internode Interaction (allow the nodes of the system to communicate, cooperate, and collaborate with other nodes when this interaction is essential), Modularity (construct the system of relatively independent but interlocking system components or system elements; also called Localized Capacity), Neutral State (allow the system to incorporate time delays that will allow human operators to consider actions to prevent further damage), Complexity Avoidance (incorporate features that enable the system to limit its own complexity to a level not more than necessary), Hidden Interactions Avoidance (incorporate features that assure that potentially harmful interactions between nodes are avoided), Redundancy [functional] (employ an architecture with two or more independent and identical branches), Redundancy [physical] (employ an architecture with two or more different branches; also called Diversity), Loose Coupling (construct the system of elements that depend on each other to the least extent practicable), Defense-in-Depth (provide multiple means to avoid failure; also called Layered Defense), Restructuring (incorporate features that allow the system to restructure itself; also known as Reorganization), and Reparability (incorporate features that allow the system to be brought up to partial or full functionality over a specified period of time and in a specified environment).

¹¹⁰ Survivability design principles are described in [Richards08]. The Survivability design principles mapped to cyber resiliency design principles in this appendix are: Prevention (suppress a future or potential future disturbance); Mobility (relocate to avoid detection by an external change agent), Concealment (reduce the visibility of a system from an external change agent), Deterrence (dissuade a rational external agent from committing a disturbance), Preemption (suppress an imminent disturbance), Avoidance (maneuver away from an ongoing disturbance), Hardness (resist deformation), Redundancy (duplicate critical system functions to increase reliability), Margin (allow extra capabilities to maintain value delivery despite losses), Heterogeneity (vary system elements to mitigate homogeneous disturbances), Distribution (separate critical system elements to mitigate local disturbances), Failure Mode Reduction (eliminate system hazards through intrinsic design: substitute, simplify, decouple, and reduce hazardous materials), Fail-Safe (prevent or delay degradation via physics of incipient failure), Evolution (alter system elements to reduce disturbance effectiveness), Containment (isolate or minimize the propagation of failure), Replacement (substitute system elements to improve value delivery), and Repair (restore the system to improve value delivery).

| STRATEGIC DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|--|--|---|
| SUPPORT AGILITY AND ARCHITECT FOR ADAPTABILITY. | <p>Motivation: Not only does the threat landscape change as adversaries evolve, so do technologies and the ways in which individuals and organizations use them. Both agility and adaptability are integral to the risk management strategy in response to the risk framing assumption that unforeseen changes will occur in the threat, technical, and operational environment through a system's lifespan.</p> <p>Guidance: Prepare for changes in the technical, operational, and threat environments. Leverage existing and emerging standards to support interoperability. Recognizing that the organization could invest in capabilities or create programs for varying purposes and with different time frames, manage risks due to dependencies or other interactions among programs or initiatives.</p> | <p>Security: Secure Evolvability, Minimized Sharing, Reduced Complexity, Secure System Modification.</p> <p>Resilience Engineering: Reorganization, Human Backup, Inter-Node Interaction.</p> <p>Survivability: Mobility, Evolution.</p> |
| REDUCE ATTACK SURFACES. | <p>Motivation: A large attack surface is difficult to defend and requires ongoing effort to monitor, analyze, and respond to anomalies. Reducing attack surfaces reduces ongoing protection scope costs and makes the adversary concentrate efforts on a small set of locations, resources, or environments that can be more effectively monitored and defended.</p> <p>Guidance: Understand the organization's attack surfaces—not only the exposed elements of systems but also people and processes. Consider how an adversary could attack development, operational, and maintenance environments. Consider attack surfaces in the cyber supply chain. Consider social media exposure and insider threats.</p> | <p>Security: Least Common Mechanism, Minimized Sharing, Reduced Complexity, Minimized Security Elements, Least Privilege, Predicate Permission.</p> <p>Resilience Engineering: Complexity Avoidance, Drift Correction.</p> <p>Survivability: Prevention, Failure Mode Reduction.</p> |
| ASSUME COMPROMISED RESOURCES. | <p>Motivation: Systems and system components, ranging from chips to software modules to running services, can be compromised for extended periods without detection. In fact, some compromises may never be detected. Systems must remain capable of meeting performance and quality requirements nonetheless.</p> <p>Guidance: Structure systems and mission or business processes to minimize the harm that could result from a specific</p> | <p>Security: Trusted Components, Self-Reliant Trustworthiness, Trusted Communications Channels.</p> <p><i>Incompatible with Security:</i> Hierarchical Protection.</p> <p>Resilience Engineering: Human Backup, Localized Capacity, Loose Coupling.</p> |

| STRATEGIC DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|--------------------------------------|---|--|
| | product or type of technology being compromised. Consider the potential for lateral movement by an adversary as well as for cascading failures. Analyze and prepare to manage the potential consequences of learning that a key component, service, or technology has been compromised or found vulnerable. | |
| EXPECT ADVERSARIES TO EVOLVE. | <p>Motivation: Advanced cyber adversaries invest time, effort, and intelligence-gathering to improve existing TTPs and develop new TTPs. Adversaries evolve in response to opportunities offered by new technologies or uses of technology, as well as to the knowledge they gain about defender TTPs. In time, the tools developed by advanced adversaries become available to less sophisticated adversaries. Therefore, systems and missions need to be resilient in the face of unexpected attacks.</p> <p>Guidance: Incorporate an adversarial perspective when analyzing architectural changes, design modifications, and changes in operational procedures and governance structures. Use cyber threat intelligence (CTI), but do not be limited by it—take a longer-term view, and expect the threat landscape to continue to change.</p> | <p>Security: Trusted Communications Channels.</p> <p>Resilience Engineering: Reorganization, Drift Correction.</p> <p>Survivability: Evolution.</p> |

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2242 Strategic design principles are driven by an organization’s risk management strategy and, in
 2243 particular, by its risk framing. Risk framing may include assumptions about the threats the
 2244 organization should be prepared for, the constraints on risk management decision-making
 2245 (including which risk response alternatives are irrelevant), and organizational priorities and
 2246 trade-offs.¹¹¹ From the standpoint of cyber resiliency, one way to express priorities is in terms of
 2247 which cyber resiliency objectives are most important. Each strategic design principle supports
 2248 the achievement of one or more cyber resiliency objectives and relates to the design principles,
 2249 concerns, or analysis processes associated with other specialty engineering disciplines. The
 2250 relationships between strategic cyber resiliency design principles, risk framing, and analytic
 2251 practices are indicated in [Table D-7](#). Relationships between design principles and other cyber
 2252 resiliency constructs are identified in [Section D.6](#).

2253

¹¹¹ See [\[SP 800-39\]](#).

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TABLE D-7: STRATEGIC DESIGN PRINCIPLES DRIVE ANALYSIS AND RELATE TO RISK MANAGEMENT

| STRATEGIC DESIGN PRINCIPLES AND ANALYTIC PRACTICES | RISK FRAMING ELEMENTS OF RISK MANAGEMENT STRATEGY |
|---|---|
| <u>FOCUS ON COMMON CRITICAL ASSETS.</u> Practices: Criticality Analysis, Business Impact Analysis (BIA), Mission Impact Analysis (MIA), Mission Thread Analysis | Threat assumptions: Conventional adversary; advanced adversary seeking path of least resistance Risk response constraints: Limited programmatic resources Risk response priorities: Anticipate , Withstand , Recover |
| <u>SUPPORT AGILITY AND ARCHITECT FOR ADAPTABILITY.</u> Practices: Analysis of standards conformance, interoperability analysis, reusability analysis | Threat assumptions: Adaptive, agile adversary Risk response constraints: Missions to be supported and mission needs can change rapidly Risk response priorities: Recover , Adapt |
| <u>REDUCE ATTACK SURFACES.</u> Practices: Supply Chain Risk Management (SCRM) analysis, vulnerability and exposure analysis, Operations Security (OPSEC) analysis, Cyber attack modeling and simulation | Threat assumptions: Conventional adversary; advanced adversary seeking path of least resistance Risk response constraints: Limited operational resources to monitor and actively defend systems Risk response priorities: Anticipate |
| <u>ASSUME COMPROMISED RESOURCES.</u> Practices: Cascading failure analysis, Insider Threat analysis, Cyber attack modeling and simulation | Threat assumptions: Advanced adversary Risk response constraints: Ability to assure the trustworthiness of system elements is limited Risk response priorities: Anticipate , Withstand |
| <u>EXPECT ADVERSARIES TO EVOLVE.</u> Practices: Adversary-driven Cyber Resiliency (ACR) analysis, Red Teaming | Threat assumptions: Advanced adversary; adversary can change TTPs and goals unpredictably Risk response priorities: Anticipate , Adapt |

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2257 Sections D.5.1.1 through D.5.1.5 provide descriptions of the *strategic* cyber resiliency principles.2258 **D.5.1.1 Focus on Common Critical Assets**

2259 A focus on critical assets (i.e., resources valued due to their importance to mission or business
 2260 accomplishment)¹¹² is central to contingency planning, continuity of operations planning,
 2261 operational resilience, and safety analysis. Critical assets can be identified using a variety of
 2262 mission-oriented analysis techniques, including Mission Impact Analysis (MIA), Business Impact
 2263 Analysis (BIA),¹¹³ Functional Dependency Network Analysis (FDNA), Crown Jewels Analysis (CJA),
 2264 and Mission Thread Analysis. In some instances, failure modes, effects, and criticality analysis
 2265 (FMECA) can reflect a safety-oriented approach.

2266 Assets that are common to multiple missions or business functions are potential high-value
 2267 targets for adversaries either because those assets are critical or because their compromise
 2268 increases the adversaries' options for lateral motion¹¹⁴ or persistence [[OMB M-19-03](#)]. Once an
 2269 asset is identified as critical or common, further analysis involves:

¹¹² Critical assets may also be referred to as high-value assets (HVA) in accordance with [[OMB M-19-03](#)].

¹¹³ See [[SP 800-34](#)].

¹¹⁴ Lateral motion refers to an adversary's ability to move transitively from one system element to another system element or in a system-of-systems from one constituent system to another constituent system.

2270 • Identifying how the asset is used in different operational contexts (e.g., normal operations,
2271 abnormal operations, crisis or emergency operations, failover). An asset that is common to
2272 multiple missions may be critical to one mission in one context but not in a second or critical
2273 to a second mission only in the second context.

2274 • Determining which properties or attributes make the asset critical (e.g., correctness, non-
2275 observability, availability) or high value (e.g., providing access to a set of critical system
2276 elements, providing information that could be used in further malicious cyber activities) and
2277 what would constitute an acceptable (e.g., safe, secure) failure mode. Again, properties that
2278 are critical to one mission may be nonessential to another, and a failure mode that is
2279 acceptable from the standpoint of security may be unacceptable from the standpoint of
2280 safety.

2281 • Determining which strategies to use to ensure critical properties, taking into consideration
2282 the different usage contexts and potential malicious cyber activities. Strategies for ensuring
2283 the correctness and non-observability properties include disabling non-critical functionality,
2284 restoring to default or known-good settings, and selectively isolating or disabling data flows
2285 to or from system components. Articulating trade-offs among critical properties and
2286 acceptable failure modes is central to effective risk management.

2287 Based on the strategy or strategies that best fit a given type of asset, the most appropriate or
2288 relevant structural design principles can be determined.

2289 This strategic design principle makes common infrastructures (e.g., networks), shared services
2290 (e.g., identity and access management services), and shared data repositories high priorities for
2291 the application of selected cyber resiliency techniques. It recognizes that the resources for risk
2292 mitigation are limited and enables systems engineers to focus resources where they will have
2293 the greatest potential impact on risk mitigation.

2294 **D.5.1.2 Support Agility and Architect for Adaptability**

2295 In Resilience Engineering, *agility* means “the effective response to opportunity and problem,
2296 within a mission” [Jackson07] [Sheard08]. In that context, resilience supports agility and
2297 counters brittleness. In the context of cyber resiliency, agility is the property of an infrastructure
2298 or a system that can be reconfigured, in which components can be reused or repurposed, and in
2299 which resources can be reallocated so that cyber defenders can define, select, and tailor cyber
2300 courses of action (CCoA) for a broad range of disruptions or malicious cyber activities. This
2301 strategy is consistent with the vision that the “infrastructure allows systems and missions to be
2302 reshaped nimbly to meet tactical goals or environment changes” [King12]. Agility enables the
2303 system and operational processes to incorporate new technologies and/or adapt to changing
2304 adversary capabilities.

2305 *Adaptability* is the property of an architecture, a design, and/or an implementation that can
2306 accommodate changes to the threat model, mission or business functions, technologies, and
2307 systems without major programmatic impacts. A variety of strategies for agility and adaptability
2308 have been defined. These include modularity and controlled interfaces to support plug-and-play,
2309 the externalization of rules and configuration data, and the removal or disabling of unused
2310 components to reduce complexity. Application of this design principle early in the system life
2311 cycle can reduce sustainment costs and modernization efforts.

2312 This design principle means that analyses of alternative architectures and designs need to
2313 search for sources of brittleness (e.g., reliance on a single operating system or communications
2314 channel, allowing single points of failure, reliance on proprietary interface standards, use of
2315 large and hard-to-analyze multi-function modules). Therefore, the analyses need to focus on
2316 [Realignment](#) and consider [Redundancy](#), [Adaptive Response](#), [Diversity](#), and the [Coordinated](#)
2317 [Protection](#) capabilities that enable cyber defenders to make effective use of these techniques. In
2318 addition, analyses need to consider where and how to use “cyber maneuver,” or moving target
2319 defenses, and [Deception](#). Finally, analyses need to consider where and how an architecture,
2320 design, or as-deployed system is bound to designated assumptions about the threat,
2321 operational, and/or technical environments.

2322 **D.5.1.3 Reduce Attack Surfaces**

2323 The term *attack surface* refers to the set of points on the boundary of a system, a system
2324 element, or an environment where an attacker can try to enter, cause an effect on, or extract
2325 data from that system, system element, or environment. The system’s attack surface can be
2326 characterized as the accessible areas where weaknesses or deficiencies (including in hardware,
2327 software, and firmware system components) provide opportunities for adversaries to exploit
2328 vulnerabilities [[SP 800-53](#)] or as its exposure to reachable and exploitable vulnerabilities: any
2329 hardware, software, connection, data exchange, service, or removable media that might expose
2330 the system to potential threat access [[DOD15](#)].

2331 Some uses of the term focus on externally exposed vulnerabilities (i.e., the attack surface of a
2332 system that connects to a network includes access control points for remote access). However,
2333 the assumption that an adversary will penetrate an organization’s systems means that internal
2334 exposures (i.e., vulnerabilities that can be reached by lateral movement within a system or
2335 infrastructure) are also part of the attack surface. Conceptually, the term *attack surface* can also
2336 cover aspects of the development, operational, and maintenance environments that an
2337 adversary can reach and that could contain vulnerabilities. The supply chain for a system can
2338 also present additional attack surfaces. More broadly, an organization can be said to have an
2339 attack surface that includes its personnel, external users of organizational systems (if any), and
2340 its supply chain both for mission or business operations and information and communications
2341 technology (ICT). To accommodate these broader interpretations of the term, the design
2342 principle refers to “attack surfaces.”

2343 This design principle is often used in conjunction with the [Focus on common critical assets](#)
2344 principle. Analysis of internal attack surfaces can reveal unplanned and unexpected paths to
2345 critical assets. It makes the identification or discovery of attack surfaces a priority in system
2346 design analyses,¹¹⁵ as well as analyses of development, configuration, and maintenance
2347 environments (e.g., by considering how using free and open-source software [FOSS] or
2348 commercial off-the-shelf [COTS] products that cannot be tailored in those environments
2349 expands attack surfaces). It may be infeasible in some architectures (e.g., Internet of Things,
2350 bring-your-own-device) or procurement environments (e.g., limited supply chain) for which the
2351 [Assume compromised resources](#) principle is highly relevant.

¹¹⁵ For example, [[SP 800-53](#)] control SA-11(6), Developer Security Testing | Attack Surface Reviews, calls for the analysis of design and implementation changes.

2352 As indicated in [Table D-8](#), several alternative strategies for reducing an attack surface can be
 2353 identified. These strategies are expressed by different controls in [\[SP 800-53\]](#) and apply different
 2354 cyber resiliency techniques. In [Table D-8](#), the **bolding** in the discussion of the control indicates
 2355 how the control supports the strategy. These strategies can be reflected by different structural
 2356 principles. For example, design decisions related to the [Maximize transience](#) and [Change or](#)
 2357 [disrupt the attack surface](#) structural principles can reduce the duration of exposure; application
 2358 of the [Limit the need for trust](#) principle can reduce exposure. While the controls in [Table D-8](#)
 2359 focus on attack surfaces within a system, the strategies apply more broadly to the attack
 2360 surfaces of a mission or an organization. For example, Operations Security (OPSEC) can reduce
 2361 exposure of the mission or organization to adversary reconnaissance. Supply chain protections
 2362 can reduce the exposure of key components to tampering.

2363 TABLE D-8: STRATEGIES FOR REDUCING ATTACK SURFACES¹¹⁶

| STRATEGY | SECURITY CONTROL SUPPORTING STRATEGY | RELATED TECHNIQUES |
|--|---|--|
| REDUCE THE EXTENT OF THE ATTACK SURFACE. | Attack surface reduction includes implementing the concept of layered defenses, applying the principles of least privilege and least functionality, deprecating unsafe functions, and applying secure software development practices, including reducing entry points available to unauthorized users, reducing the amount of code that executes, and eliminating application programming interfaces (APIs) that are vulnerable to cyber attacks. SA-15(5) DEVELOPMENT PROCESS, STANDARDS, AND TOOLS ATTACK SURFACE REDUCTION [SP 800-53] | Coordinated Protection Privilege Restriction Realignment |
| REDUCE THE EXPOSURE (STRUCTURAL ACCESSIBILITY) OF THE ATTACK SURFACE. | Attack surface reduction includes implementing the concept of layered defenses and applying the principles of least privilege and least functionality. SA-15(5) DEVELOPMENT PROCESS, STANDARDS, AND TOOLS ATTACK SURFACE REDUCTION [SP 800-53] | Privilege Restriction Coordinated Protection |
| | Component isolation reduces the attack surface of organizational systems. SC-7(20) BOUNDARY PROTECTION DYNAMIC ISOLATION AND SEGREGATION [SP 800-53] | Adaptive Response Segmentation |
| REDUCE THE DURATION (TEMPORAL ACCESSIBILITY) OF ATTACK SURFACE EXPOSURE. | The implementation of non-persistent components and services mitigates risk from advanced persistent threats (APTs) by reducing the targeting capability of adversaries (i.e., window of opportunity and available attack surface) to initiate and complete attacks. SI-14 NON-PERSISTENCE [SP 800-53] | Non-Persistence |

2364
 2365 This design principle in conjunction with the [Support agility and architect for adaptability](#)
 2366 principle motivates analyses of the effects on the attack surface of a system-of-interest due to
 2367 changes in its overall environment. Analyses consider changes in the organizational, operational,

¹¹⁶ The security control supporting strategy includes examples and excerpts from relevant [\[SP 800-53\]](#) controls.

2368 and programmatic environments, which can change physical, supply chain, personnel, technical,
2369 and procedural aspects of the attack surface, as well as technical aspects.

2370 **D.5.1.4 Assume Compromised Resources**

2371 A significant number of system architectures treat many, if not all, resources as non-malicious.
2372 This assumption is particularly prevalent in cyber-physical systems (CPS) and Internet of Things
2373 (IoT) architectures [Folk15]. However, systems and their components, ranging from chips to
2374 software modules to running services, can be compromised for extended periods without
2375 detection [DSB13]. In fact, some compromises may never be detected. Thus, the assumption
2376 that some system resources have been compromised is prudent. While the assumption that
2377 some resources cannot be trusted is well-established from the standpoint of security (i.e., the
2378 compromised resources cannot be trusted to follow established security policies), the concept
2379 of trustworthiness is broader. By compromising a resource, an adversary can affect its reliability,
2380 the ability to enforce other policies, or the safety of the larger system or environment of which
2381 the resource is a part or can use the resource in an attack on other systems [SP 1500-201]
2382 [NIST16](#).

2383 This design principle implies the need for analysis of how the system architecture reduces the
2384 potential consequences of a successful compromise—in particular, the duration and degree of
2385 adversary-caused disruption and the speed and extent of malware propagation. An increasing
2386 number of modeling and simulation techniques support the analysis of the potential systemic
2387 consequences stemming from the compromise of a given resource or set of resources. Such
2388 analysis includes identifying different types or forms of systemic consequences (e.g., unreliable
2389 or unpredictable behavior of services, unreliable or unpredictable availability of capabilities, or
2390 data of indeterminate quality) and subsequently linking these systemic consequences to mission
2391 consequences (e.g., mission failure, safety failure) or organizational consequences (e.g., loss of
2392 trust or reputation).

2393 **D.5.1.5 Expect Adversaries to Evolve**

2394 Advanced cyber adversaries invest time, effort, and intelligence-gathering to improve existing
2395 TTPs and develop new TTPs. Adversaries evolve in response to opportunities offered by new
2396 technologies or uses of technology, as well as to the knowledge they gain about defender TTPs.
2397 In (increasingly short) time, the tools developed by advanced adversaries become available to
2398 less sophisticated adversaries. Therefore, systems and missions need to be resilient in the face
2399 of unexpected attacks. This design principle supports a risk management strategy that includes
2400 and goes beyond the common practice of searching for and seeking ways to remediate known
2401 vulnerabilities (or classes of vulnerabilities). A system that has been hardened in the sense of
2402 remediating known vulnerabilities will remain exposed to evolving adversaries.

2403 This design principle implies the need for analyses in which the adversary perspective is
2404 explicitly represented by intelligent actors who can play the role of an adaptive or evolving
2405 adversary. For implemented systems, such analyses are typically part of *red teaming* or *war
2406 gaming*. Analyses can use threat intelligence or repositories of attack patterns (e.g., ATT&CK
2407 [\[MITRE18\]](#), CAPEC [\[MITRE07\]](#)) to provide concrete examples, but care should be taken not to be
2408 constrained by those examples. Voice of the Adversary (VoA) is a design analysis technique in
2409 which one or more team members play the role of an adversary to critique alternatives by
2410 taking into consideration possible goals, behaviors, and cyber effects assuming varying degrees

2411 of system access or penetration. This type of design analysis can use models or taxonomies of
 2412 adversary behaviors (e.g., the cyber attack life cycle or cyber kill chain models [[Hutchins11](#)],
 2413 CAPEC [[MITRE07](#)] or ATT&CK [[MITRE18](#)] classes) and languages or taxonomies of cyber effects
 2414 (e.g., [[Temin10](#)]).

2415 This design principle also highlights the value of the [Deception](#) and [Diversity](#) techniques.
 2416 Deception can cause adversaries to reveal their TTPs prematurely from the perspective of their
 2417 cyber campaign plans, enabling defenders to develop countermeasures or defensive TTPs.
 2418 Diversity can force an adversary to develop a range of TTPs to achieve the same objectives.

2419 **D.5.2 Structural Design Principles**

2420 Structural cyber resiliency design principles guide and inform design and implementation
 2421 decisions throughout the system life cycle. As indicated in [Table D-9](#), many of the structural
 2422 design principles are consistent with or leverage the design principles for security and/or
 2423 resilience.¹¹⁷ The first four design principles are closely related to protection strategies and
 2424 security design principles and can be applied in mutually supportive ways. The next three design
 2425 principles are closely related to design principles for resilience engineering and survivability; are
 2426 driven by the concern for an operational environment (including cyber threats), which changes
 2427 on an ongoing basis; and are closely related to design principles for evolvability. The final four
 2428 principles are strongly driven by the need to manage the effects of malicious cyber activities,
 2429 even when those activities are not observed. Descriptions of how structural design principles are
 2430 applied or could be applied to a system-of-interest can help stakeholders understand how their
 2431 concerns are being addressed.

2432 **TABLE D-9: STRUCTURAL CYBER RESILIENCY DESIGN PRINCIPLES**

| STRUCTURAL DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|--------------------------------|---|--|
| LIMIT THE NEED FOR TRUST. | Limiting the number of system elements that need to be trusted (or the length of time for which an element needs to be trusted) reduces the level of effort needed for assurance, ongoing protection, and monitoring. | Security: Least Common Mechanism, Trusted Components, Inverse Modification Threshold, Minimized Security Elements, Least Privilege, Predicate Permission, Self-Reliant Trustworthiness, Trusted Communications Channels. Resilience Engineering: Localized Capacity, Loose Coupling. Survivability: Prevention. |
| CONTROL VISIBILITY AND USE. | Controlling what can be discovered, observed, and used increases the effort needed by an adversary seeking to expand its foothold in or increase its impacts on systems containing cyber resources. | Security: Clear Abstraction, Least Common Mechanism, Least Privilege, Predicate Permission. Resilience Engineering: Localized Capacity, Loose Coupling. Survivability: Concealment, Hardness. |
| CONTAIN AND EXCLUDE BEHAVIORS. | Limiting what can be done and where actions can be taken reduces the possibility or extent of the spread of | Security: Trusted Components, Least Privilege, Predicate Permission. |

¹¹⁷ The relationship between strategic and structural cyber resiliency design principles is presented in [Table D-10](#).

| STRUCTURAL DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|--|--|--|
| | compromises or disruptions across components or services. | Resilience Engineering: Localized Capacity, Loose Coupling. Survivability: Preemption, Hardness, Distribution. |
| LAYER DEFENSES AND PARTITION RESOURCES. | The combination of defense-in-depth and partitioning increases the effort required by an adversary to overcome multiple defenses. | Security: Modularity and Layering, Partially Ordered Dependencies, Minimized Sharing, Self-Reliant Trustworthiness, Secure Distributed Composition. Resilience Engineering: Layered Defense. Survivability: Hardness, Fail-Safe |
| PLAN AND MANAGE DIVERSITY. | Diversity is a well-established resilience technique that removes single points of attack or failure. However, architectures and designs should take cost and manageability into consideration to avoid introducing new risks. | Resilience Engineering: Absorption, Repairability. Survivability: Heterogeneity. |
| MAINTAIN REDUNDANCY. | Redundancy is key to many resilience strategies but can degrade over time as configurations are updated or connectivity changes. | Resilience Engineering: Absorption, Physical Redundancy, Functional Redundancy. Survivability: Redundancy, Margin. |
| MAKE RESOURCES LOCATION-VERSATILE. | A resource bound to a single location (e.g., a service running only on a single hardware component, a database located in a single datacenter) can become a single point of failure and thus a high-value target. | Resilience Engineering: Localized Capacity, Repairability. Survivability: Mobility, Avoidance, Distribution. |
| LEVERAGE HEALTH AND STATUS DATA. | Health and status data can be useful in supporting situational awareness, indicating potentially suspicious behaviors, and predicting the need for adaptation to changing operational demands. | Resilience Engineering: Drift Correction, Inter-Node Interaction. |
| MAINTAIN SITUATIONAL AWARENESS. | Situational awareness, including the awareness of possible performance trends and the emergence of anomalies, informs decisions about cyber courses of action to ensure mission completion. | Resilience Engineering: Drift Correction, Inter-Node Interaction. |
| MANAGE RESOURCES (RISK-) ADAPTIVELY. | Risk-adaptive management supports agility and provides supplemental risk mitigation throughout critical operations despite disruptions or outages of components. | Security: Trusted Components, Hierarchical Trust, Inverse Modification Threshold, Secure Distributed Composition, Trusted Communications Channels, Secure Defaults, Secure Failure and Recovery. Resilience Engineering: Reorganization, Repairability, Inter-Node Interaction. Survivability: Avoidance. |

| STRUCTURAL DESIGN PRINCIPLES | KEY IDEAS | RELATED DESIGN PRINCIPLES FROM OTHER DISCIPLINES |
|---|--|--|
| MAXIMIZE TRANSIENCE. | Use of transient system elements minimizes the duration of exposure to adversary activities, while periodically refreshing to a known (secure) state can expunge malware or corrupted data. | Resilience Engineering: Localized Capacity, Loose Coupling. Survivability: Avoidance. |
| DETERMINE ONGOING TRUSTWORTHINESS. | Periodic or ongoing verification and/or validation of the integrity or correctness of data or software can increase the effort needed by an adversary seeking to modify or fabricate data or functionality. Similarly, periodic or ongoing analysis of the behavior of individual users, system components, and services can increase suspicion and trigger responses such as closer monitoring, more restrictive privileges, or quarantine. | Security: Self-Reliant Trustworthiness, Continuous Protection, Secure Metadata Management, Self-Analysis, Accountability and Traceability. Resilience Engineering: Neutral State. Survivability: Fail-Safe. |
| CHANGE OR DISRUPT THE ATTACK SURFACE. | Disruption of the attack surface can cause the adversary to waste resources, make incorrect assumptions about the system or the defender, or prematurely launch attacks or disclose information. | Resilience Engineering: Drift Correction Survivability: Mobility, Deterrence, Preemption, Avoidance. |
| MAKE THE EFFECTS OF DECEPTION AND UNPREDICTABILITY USER-TRANSPARENT. | Deception and unpredictability can be highly effective techniques against an adversary, leading the adversary to reveal its presence or TTPs or to waste effort. However, when improperly applied, these techniques can also confuse users. | Security: Efficiently Mediated Access, Performance Security, Human Factored Security, Acceptable Security. Survivability: Concealment. |

2433

2434

2435 The selection of structural design principles is driven by strategic design principles, as shown in
 2436 [Table D-10](#).

2437

TABLE D-10: STRATEGIC DESIGN PRINCIPLES DRIVE STRUCTURAL DESIGN PRINCIPLES

| STRUCTURAL DESIGN PRINCIPLES | STRATEGIC DESIGN PRINCIPLES | | | | |
|---|---------------------------------|--|------------------------|------------------------------|------------------------------|
| | Focus on common critical assets | Support agility and architect for adaptability | Reduce attack surfaces | Assume compromised resources | Expect adversaries to evolve |
| <u>LIMIT THE NEED FOR TRUST.</u> | | | X | X | |
| <u>CONTROL VISIBILITY AND USE.</u> | X | | X | X | |
| <u>CONTAIN AND EXCLUDE BEHAVIORS.</u> | X | | | X | X |

| | | | | | |
|---|---|---|---|---|---|
| <u>LAYER DEFENSES AND PARTITION RESOURCES.</u> | X | | | X | |
| <u>PLAN AND MANAGE DIVERSITY.</u> | X | X | | X | |
| <u>MAINTAIN REDUNDANCY.</u> | X | X | | X | |
| <u>MAKE RESOURCES LOCATION-VERSATILE.</u> | X | X | | | X |
| <u>LEVERAGE HEALTH AND STATUS DATA.</u> | X | X | | X | X |
| <u>MAINTAIN SITUATIONAL AWARENESS.</u> | X | | | | X |
| <u>MANAGE RESOURCES (RISK-)ADAPTIVELY.</u> | X | X | | | X |
| <u>MAXIMIZE TRANSIENCE.</u> | | | X | X | X |
| <u>DETERMINE ONGOING TRUSTWORTHINESS.</u> | X | | | X | X |
| <u>CHANGE OR DISRUPT THE ATTACK SURFACE.</u> | | | X | X | X |
| <u>MAKE THE EFFECTS OF DECEPTION AND UNPREDICTABILITY USER-TRANSPARENT.</u> | | X | X | | |

2438

2439 Structural design principles provide guidance for design decisions intended to reduce risk.¹¹⁸
 2440 This guidance affects the selection and the application of cyber resiliency techniques. [Table D-15](#)
 2441 describes the relationship between structural design principles and cyber resiliency techniques.
 2442 [Table D-11](#) briefly describes the structural design principles and identifies the intended effects
 2443 of each structural design principle on risk.

2444

TABLE D-11: STRUCTURAL DESIGN PRINCIPLES AND EFFECTS ON RISK

| STRUCTURAL DESIGN PRINCIPLES | INTENDED EFFECTS ON RISK |
|------------------------------------|--|
| <u>LIMIT THE NEED FOR TRUST.</u> | Reduce the likelihood of harm due to malice, error, or failure. Discussion: Limit the number of system elements that need to be trusted (or the length of time an element needs to be trusted). This reduces the level of effort needed for assurance, ongoing protection, and monitoring. This principle is consistent with ZT tenets. |
| <u>CONTROL VISIBILITY AND USE.</u> | Reduce the likelihood of occurrence of adversarial events; reduce the likelihood of harm due to malice, error, or failure. Discussion: Control what can be discovered, observed, and used. This increases the effort needed by an adversary seeking to expand a foothold or increase impacts. This principle is consistent with ZT tenets. |

¹¹⁸ Harm to a cyber resource can take the form of degradation or disruption of functionality or performance; exfiltration or exposure of information; modification, corruption, or fabrication of information (including software, mission or business information, and configuration data); or usurpation or misuse of system resources. Unless otherwise specified, all forms of harm to systems containing cyber resources are addressed.

| STRUCTURAL DESIGN PRINCIPLES | INTENDED EFFECTS ON RISK |
|--|---|
| <u>CONTAIN AND EXCLUDE BEHAVIORS.</u> | <p>Reduce the likelihood of occurrence of adversarial events; reduce the likelihood of harm due to malice, error, or failure.</p> <p>Discussion: Limit what and where actions can be taken. This reduces the possibility or extent of the spread of compromises or disruptions across components or services. This principle is consistent with ZT tenets.</p> |
| <u>LAYER DEFENSES AND PARTITION RESOURCES.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure; reduce the extent of harm.</p> <p>Discussion: The combination of defense-in-depth and partitioning increases the effort required by an adversary to overcome multiple defenses. This principle is consistent with ZT tenets.</p> |
| <u>PLAN AND MANAGE DIVERSITY.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure; reduce the extent of disruption.</p> <p>Discussion: Diversity is a well-established system resilience technique that removes single points of attack or failure. However, it can also increase attack surfaces. The development of architectures and designs should take cost and complexity into consideration to identify and manage new risks.</p> |
| <u>MAINTAIN REDUNDANCY.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure; reduce the extent of disruption or degradation.</p> <p>Discussion: Redundancy is key to many system resilience strategies but can degrade over time as configurations are updated or connectivity changes.</p> |
| <u>MAKE RESOURCES LOCATION-VERSATILE.</u> | <p>Reduce the likelihood of occurrence of adversarial events; reduce the extent of disruption or degradation.</p> <p>Discussion: A resource bound to a single location (e.g., a service running only on a single hardware component, a database located in a single datacenter) can become a single point of failure and thus a high-value target.</p> |
| <u>LEVERAGE HEALTH AND STATUS DATA.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure by enabling responses to changes in system state; reduce the extent of harm by enabling the detection of and response to indicators of damage.</p> <p>Discussion: Health and status data can be useful in supporting situational awareness, indicating potentially suspicious behaviors, and predicting the need for adaptation to changing operational demands.</p> |
| <u>MAINTAIN SITUATIONAL AWARENESS.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure by enabling responses to indicators; reduce the extent of harm by enabling the detection of and response to indicators of damage.</p> <p>Discussion: Situational awareness, including awareness of possible performance trends and the emergence of anomalies, informs decisions about cyber courses of action to ensure mission completion.</p> |

| STRUCTURAL DESIGN PRINCIPLES | INTENDED EFFECTS ON RISK |
|---|--|
| <u>MANAGE RESOURCES (RISK-) ADAPTIVELY.</u> | <p>Reduce the likelihood of harm due to malice, error, or failure by enabling responses to changes in the operational environment; reduce the extent of harm.</p> <p>Discussion: Risk-adaptive management supports agility and provides supplemental risk mitigation throughout critical operations despite disruptions or outages of components.</p> |
| <u>MAXIMIZE TRANSIENCE.</u> | <p>Reduce the likelihood of occurrence by reducing the time during which an adverse event could occur; reduce the likelihood of harm due to malice, error, or failure by reducing the time during which an event could result in harm.</p> <p>Discussion: The use of transient system elements (e.g., data, services, connectivity) minimizes the duration of exposure to adversary activities. Periodically refreshing to a known (secure) state can expunge malware or corrupted data.</p> |
| <u>DETERMINE ONGOING TRUSTWORTHINESS.</u> | <p>Reduce the likelihood of harm due to corrupted, modified, or fabricated information by enabling untrustworthy information to be identified; reduce the extent of harm by reducing the propagation of untrustworthy information.</p> <p>Discussion: Do not assume that the properties of a resource, service, process, or connection are stable over time. Perform periodic or ongoing verification and/or validation of properties related to trustworthiness, and perform ongoing monitoring and analysis of behavior. This principle is consistent with ZT tenets.</p> |
| <u>CHANGE OR DISRUPT THE ATTACK SURFACE.</u> | <p>Reduce the likelihood of occurrence by removing the circumstances in which an adversarial event is feasible; reduce the likelihood of harm due to adversarial events by making such events ineffective.</p> <p>Discussion: Disruption of the attack surface can cause the adversary to waste resources, make incorrect assumptions about the system or the defender, prematurely launch attacks, or disclose information.</p> |
| <u>MAKE THE EFFECTS OF DECEPTION AND UNPREDICTABILITY USER-TRANSPARENT.</u> | <p>Reduce the likelihood of the occurrence of errors; when Deception techniques are applied, reduce the likelihood of the occurrence of adversarial events.</p> <p>Discussion: Deception and unpredictability can be highly effective techniques against an adversary, leading the adversary to reveal its presence or TTPs or to waste effort. However, when improperly applied, these techniques can also confuse users.</p> |

2445

2446 Sections D.5.2.1 through D.5.2.14 provide more detailed descriptions of the 14 structural cyber
 2447 resiliency principles.

2448 **D.5.2.1 Limit the Need for Trust**

2449 Trustworthiness can be defined as a state in which an entity is worthy of being trusted to fulfill
 2450 whatever critical requirements may be needed for a component, subsystem, system, network,
 2451 application, mission, enterprise, or other entity [Neumann04]. Trustworthiness has also been
 2452 defined as the attribute of an entity that provides confidence to others of the qualifications,
 2453 capabilities, and reliability of that entity to perform specific tasks and fulfill assigned

2454 responsibilities [[CNSSI 4009](#)]. Assertions of trustworthiness (e.g., “this software can be relied
2455 upon to enforce the following security policies with a high level of confidence”) are meaningless
2456 without some form of verification, validation, or demonstration (e.g., design analysis, testing). In
2457 the absence of some credible form of assurance (which can be costly and invalidated by changes
2458 in the system or the environment), assertions of trustworthiness constitute assumptions.
2459 Reducing the size of the set of trusted entities (whether individuals, software components, or
2460 hardware components) by minimizing assumptions about what is or can be trusted reduces the
2461 attack surface and lowers assurance costs.

2462 The application of this design principle is most effective early in the system life cycle when the
2463 motivation of the [Prevent/Avoid](#) objective is clearest. When a system already exists, changes to
2464 the operational concept (consistent with the [Transform](#) objective) or the system architecture
2465 (applying the [Re-Architect](#) objective and the [Realignment](#) technique) can increase costs. One
2466 approach to applying this design principle (using the [Coordinated Protection](#) and [Privilege](#)
2467 [Restriction](#) techniques) is through limitations on inheritance so that privileges or access rights
2468 associated with one class of system component are not automatically propagated to classes or
2469 instances created from the original one. While limitations on inheritance can initially increase
2470 the burden on developers or administrators, they can also reduce the complexity associated
2471 with multiple inheritance.

2472 This design principle supports the strategic design principles of [Reduce attack surfaces](#) and
2473 [Assume compromised resources](#). However, its application increases the difficulty of applying the
2474 [Support agility and architect for adaptability](#) strategic design principle. This design principle can
2475 also be used in conjunction with [Determine ongoing trustworthiness](#). If a system element is
2476 assumed or required to have a given level of trustworthiness, some attestation mechanism is
2477 needed to verify that it has and continues to retain that trustworthiness level. Minimizing the
2478 number of elements with trustworthiness requirements reduces the level of effort involved in
2479 determining ongoing trustworthiness. Finally, this design principle can be used in conjunction
2480 with [Plan and manage diversity](#). The managed use of multiple sources of system elements,
2481 services, or information can enable behavior or data quality to be validated by comparison.

2482 **D.5.2.2 Control Visibility and Use**

2483 Controlling visibility counters adversary attempts at reconnaissance from outside or within the
2484 system. Thus, the adversary must exert greater effort to identify potential targets, whether for
2485 exfiltration, modification, or disruption. Ther visibility of data can be controlled by mechanisms
2486 such as encryption, data hiding, or data obfuscation. Visibility into how some resources are used
2487 can also be controlled directly, such as by adding chaff to network traffic. Visibility into the
2488 supply chain, development process, or system design can be limited via operations security
2489 (OPSEC), deception [[Heckman15](#)], and split or distributed design and manufacturing. Process
2490 obfuscation is an area of active research. An increasing number and variety of deception
2491 technologies (e.g., deception nets) can be applied at the system level.

2492 Controlling use counters adversary activities and actions in the *Control*, *Execute*, and *Maintain*
2493 phases of the cyber attack life cycle [[MITRE18](#)]. To limit visibility or control use, access to system
2494 resources can be controlled from the perspectives of multiple security disciplines, including
2495 physical, logical (see the discussion of privileges below), and hybrid (e.g., physical locations in a
2496 geographically distributed system or in a complex, embedded system). Restrictions on access
2497 and use can be guided by information sensitivity, as in standard security practices. Restrictions

2498 can also be based on criticality (i.e., the importance to achieving mission objectives). While
2499 some resources can be determined to be mission-critical or mission-essential *a priori*, the
2500 criticality of other resources can change dynamically. For example, a resource that is vital to one
2501 phase of mission processing can become unimportant after that phase is completed.

2502 Many systems or system components provide the capability to define and manage privileges
2503 associated with software, services, processes, hardware, communications channels, and
2504 individual users. The assignment of privileges should ideally reflect judgments of operational
2505 need (e.g., need-to-know, need-to-use) as well as trustworthiness. The restriction of privileges is
2506 well established as a security design principle (i.e., least privilege). Privilege restrictions force
2507 adversaries to focus efforts on a restricted set of targets, which can be assured (in the case of
2508 software), validated (in the case of data), or monitored (in the case of individuals, processes,
2509 communications channels, and services). [Non-Persistence](#) and [Segmentation](#) can also limit
2510 visibility. Thus, this principle can be applied in conjunction with the [Contain and exclude](#)
2511 [behaviors](#) and [Maximize transience](#) principles.

2512 **D.5.2.3 Contain and Exclude Behaviors**

2513 The behavior of a system or system element—including what resources it uses, which systems
2514 or system elements it interacts with, or when it takes a given action—can vary based on many
2515 legitimate circumstances. However, analysis of the organizational missions or business functions
2516 and the processes that carry out those missions and functions [[SP 800-39](#)] can identify some
2517 behaviors that are always unacceptable and others that are acceptable only under specific
2518 circumstances. Therefore, excluding behaviors prevents them from having undesirable
2519 consequences. Behaviors can be excluded *a priori* with varying degrees of assurance, from
2520 removing functionality to restricting functionality or use, with trade-offs between assurance and
2521 flexibility. For example, user activity outside of specific time windows can be precluded. In
2522 addition, behaviors can be interrupted based on ongoing monitoring when that monitoring
2523 provides a basis for suspicion.

2524 Containing behaviors involves restricting the set of resources or system elements that can be
2525 affected by the behavior of a given system element. Such restrictions can but do not necessarily
2526 involve a temporal aspect. Containment can be achieved *a priori*, via predefined privileges and
2527 segmentation. Alternately, or perhaps additionally, [Adaptive Response](#) and [Dynamic Isolation](#)
2528 can be applied. For example, a sandbox or deception environment can be dynamically created in
2529 response to suspicious behavior, and subsequent activities can be diverted there.

2530 **D.5.2.4 Layer Defenses and Partition Resources**

2531 *Defense-in-depth* is the integration of people, technology, and operations capabilities to
2532 establish variable barriers across multiple layers and missions [[CNSSI 4009](#)] and is a well-
2533 established security strategy. It describes security architectures constructed through the
2534 application of multiple mechanisms to create a series of barriers to prevent, delay, or deter an
2535 attack by an adversary [[SP 800-160 v1](#)]. Multiple mechanisms to achieve the same objective or
2536 provide equivalent functionality can be used at a single layer (e.g., different COTS firewalls to
2537 separate zones in a DMZ) or at different layers (e.g., detection of suspicious behavior at the
2538 application, operating system, and network layers). To avoid inconsistencies that could result in
2539 errors or vulnerabilities, such (multiple) mechanisms should be managed consistently.

2540 Layering defenses restricts the adversary's movement vertically in a layered security
2541 architecture (i.e., a defense at one layer prevents a compromise at an adjacent layer from
2542 propagating). Partitioning (i.e., separating sets of resources into effectively separate systems)
2543 with controlled interfaces (e.g., cross-domain solutions) between them restricts the lateral
2544 movement of the adversary. Partitioning can limit the adversary's visibility (see [Control visibility](#)
2545 and [use](#)) and serve to [Contain and exclude behaviors](#). Partitioning can be based on policy and
2546 administration, as in security domains [[SP 800-160 v1](#)], or be informed by the organizational
2547 missions or business functions that the system elements in the partition support. Partitions can
2548 be implemented physically, logically, at the network layer, or within a platform (e.g., via hard or
2549 soft partitioning). Partitioning may involve limiting resource-sharing or making fewer resources
2550 common. If resources are replicated, the [Maintain redundancy](#) principle should be applied.

2551 **D.5.2.5 Plan and Manage Diversity**

2552 [Diversity](#) (usually in conjunction with [Redundancy](#) [[Sterbenz14](#)]) is a well-established technique
2553 for improving system resilience [[Sterbenz10](#), [Höller15](#)]. For cyber resiliency, [Diversity](#) avoids the
2554 risk of system homogeneity, in which the compromise of one component can propagate to all
2555 other similar components. [Diversity](#) offers the benefit of providing alternative ways to deliver
2556 required functionality so that if a component is compromised, one or more alternative
2557 components that provide the same functionality can be used.

2558 Multiple approaches to diversity can be identified. These include architectural diversity; design
2559 diversity; synthetic (or automated) diversity;¹¹⁹ information diversity; diversity of command,
2560 control, and communications (C3) paths (including out-of-band communications); geographic
2561 diversity;¹²⁰ supply chain diversity [[SP 800-160 v1](#)] [[Bodeau15](#)]; and diversity in operating
2562 procedures. In addition, some incidental architectural diversity often results from procurement
2563 over time and differing user preferences. Incidental diversity is often more apparent than real
2564 (i.e., different products can present significantly different interfaces to administrators or users
2565 while incorporating identical components).

2566 However, diversity can be problematic in several ways. First, it can increase the attack surface of
2567 the system. Rather than trying to compromise a single component and propagate across all such
2568 components, an adversary can attack any component in the set of alternatives, looking for a
2569 path of least resistance to establish a foothold. Second, it can increase demands on developers,
2570 system administrators, maintenance staff, and users by forcing them to deal with multiple
2571 interfaces to equivalent components. This can result in increased system life cycle costs¹²¹ and
2572 increase the risk that inconsistencies will be introduced, particularly if the configuration
2573 alternatives for the equivalent components are organized differently. Third, diversity can be
2574 more apparent than real (e.g., different implementations of the same mission functionality all
2575 running on the same underlying operating system, applications that reuse selected software
2576 components). Thus, analysis of the architectural approach to using diversity is critical. For
2577 embedded systems, some approaches to diversity raise a variety of research challenges. Finally,

¹¹⁹ Synthetic diversity in conjunction with randomization, a form of [Unpredictability](#), is a form of Moving Target Defense (MTD).

¹²⁰ Geographic diversity can be used to support the [Make resources location-versatile](#) structural design principle.

¹²¹ These costs have historically been acceptable in some safety-critical systems.

2578 the effectiveness of diversity against adversaries is not an absolute, and an analysis of diversity
2579 strategies is needed to determine the best alternative in the context of adversary TTPs.

2580 Given these considerations, this design principle calls for the use of [Diversity](#) in system
2581 architecture and design to also take manageability into consideration. It also calls for the
2582 consideration of diversity in operational processes and practices, including non-cyber
2583 alternatives such as out-of-band measures [[SP 800-53](#)] for critical capabilities. To reduce cost
2584 and other impacts, this design principle is most effective when used in conjunction with the
2585 [Focus on common critical assets](#) strategic design principle and the [Maintain redundancy](#) and
2586 [Layer and partition defenses](#) structural principles. Measurements related to this design principle
2587 can focus on the degree of diversity, the degree of manageability, or both.

2588 **D.5.2.6 *Maintain Redundancy***

2589 [Redundancy](#) is a well-established design principle in Resilience Engineering and Survivability
2590 [[Sterbenz10](#)]. Approaches to [Redundancy](#) include surplus capacity and replication (e.g., cold
2591 spares, hot or inline spares) and can be implemented in conjunction with backup and failover
2592 procedures. It can enhance the availability of critical capabilities but requires that redundant
2593 resources be protected.

2594 Because malware can propagate across homogeneous resources, [Redundancy](#) for cyber
2595 resiliency should be applied in conjunction with [Diversity](#) and considered at multiple levels or
2596 layers in a layered architecture [[Sterbenz14](#)]. However, [Redundancy](#) can increase complexity
2597 and present scalability challenges when used in conjunction with [Diversity](#).

2598 The extent of [Redundancy](#) is established and maintained through analysis that looks for single
2599 points of failure and shared resources. Trends to convergence can undermine [Redundancy](#). For
2600 example, an organization using Voice over Internet Protocol (VOIP) for its phone system cannot
2601 assert alternate communications paths for phone, email, and instant messaging.

2602 Because maintaining surplus capacity or spare components increases system life cycle costs, this
2603 design principle is most effective when used in conjunction with the [Focus on common critical](#)
2604 [assets](#) strategic principle, as well as the [Plan and manage diversity](#) and [Layer and partition](#)
2605 [defenses](#) structural principles.

2606 **D.5.2.7 *Make Resources Location-Versatile***

2607 Location-versatile resources do not require a fixed location and can be relocated or
2608 reconstituted to maximize performance, avoid disruptions, and better avoid becoming a high-
2609 value target for an adversary. Different approaches can be used to provide location-versatile
2610 resources, including virtualization, replication, distribution (of functionality or stored data),
2611 physical mobility, and functional relocation. Replication is a well-established approach for high-
2612 availability systems using multiple, parallel processes, and high-availability data (sometimes
2613 referred to as data resilience) with database sharding¹²² (although this can present security
2614 challenges).

¹²² A database *shard* is a horizontal partition of data in a database. Each individual partition is referred to as a shard or database shard. Each shard is held on a separate database server instance to spread the load.

2615 Replication and distribution can be across geographic locations, hardware platforms, or (in the
2616 case of services) virtual machines. While replication can take the form of redundancy, it can also
2617 involve providing ways to reconfigure system resources to provide equivalent functionality. Data
2618 virtualization (i.e., data management that enables applications to retrieve and use data without
2619 specific knowledge of the location or format) supports distribution and reduces the likelihood
2620 that local (persistent and unmaintained) data stores will proliferate. Composable services enable
2621 the alternative reconstitution of mission capabilities, and diverse information sources can be
2622 used for the alternative reconstitution of mission or business data.

2623 Application of this principle involves the use of [Dynamic Positioning](#), often in conjunction with
2624 [Redundancy](#) and/or [Diversity](#). This principle supports the [Support agility and architect for](#)
2625 [adaptability](#) strategic principle and can be employed in conjunction with the [Maximize](#)
2626 [transience](#) and [Change or disrupt the attack surface](#) structural principles. Some approaches to
2627 the reconstitution of mission capabilities can conflict with the [Control visibility and use](#)
2628 structural principle.

2629 **D.5.2.8 Leverage Health and Status Data**

2630 In some architectures, many system components are security-unaware, incapable of enforcing a
2631 security policy (e.g., an access control policy), and therefore incapable of monitoring policy
2632 compliance (e.g., auditing or alerting to unauthorized access attempts). However, most system
2633 components provide health and status data to indicate component availability or unavailability
2634 for use. These may include components of CPS (particularly components in space systems) and
2635 in the emerging IoT. In addition, system components present health and status data to providers
2636 (e.g., application or service on a virtual platform in a cloud to a cloud provider) or service-
2637 providing components (e.g., application to operating system, device to network) so that the
2638 components can allocate and scale resources effectively. Monitoring data, including health and
2639 status data, from multiple layers or types of components in the architecture can help identify
2640 potential problems early so they can be averted or contained.

2641 As architectural convergence between information technology (IT) and operational technology
2642 (OT) or the IoT increases [[SP 1500-201](#)], application of this structural principle will support the
2643 [Expect adversaries to evolve](#) strategic principle. Given the increasing number and variety of
2644 “smart” components in the IoT, application of this principle may be driven by the [Focus on](#)
2645 [common critical assets](#) principle. In addition, components can erroneously or maliciously report
2646 health and status data by design or due to compromise. Thus, application of this principle may
2647 be more effective in conjunction with the [Determine ongoing trustworthiness](#) principle.

2648 **D.5.2.9 Maintain Situational Awareness**

2649 For security and cyber resiliency, situational awareness encompasses awareness of *system*
2650 *elements, threats, and mission dependencies* on system elements.¹²³ An awareness of system
2651 elements can rely on security status assessments, security monitoring, and performance
2652 monitoring and can be achieved in conjunction with the [Leverage health and status data](#) design

¹²³ As a foundational capability of a Security Operations Center (SOC), situational awareness provides “regular, repeatable repackaging and redistribution of the SOC’s knowledge of constituency assets, networks, threats, incidents, and vulnerabilities to constituents. This capability goes beyond cyber intel distribution, enhancing constituents’ understanding of the cybersecurity posture of the constituency and portions thereof, driving effective decision-making at all levels [[Zimmerman14](#)].”

principle. An awareness of threats involves ingesting and using threat intelligence and recognizing that adversaries evolve. An awareness of system elements and threats (via gathered data, correlated data, and processing capabilities) can be centralized or distributed and either enterprise-internal or cross-enterprise (e.g., via a managed security service provider).

An awareness of mission dependencies can be determined *a priori* as part of system design (e.g., using CJA, MIA, or BIA). Alternately or additionally, mission dependencies can be identified during mission operations by tracking and analyzing resource use. This more dynamic approach supports agility, adaptability, and capabilities to [Control visibility and use](#) and [Contain and exclude behaviors](#). While cyber situational awareness remains an active area of research, analytic capabilities are increasingly being offered, and cyber situational awareness is maturing through tailored applications in specific environments.

D.5.2.10 Manage Resources (Risk-) Adaptively

Risk-adaptive management has been developed in multiple contexts. Cybersecurity mechanisms include risk-adaptive access control (RAdAC) for systems—highly adaptive cybersecurity services (HACS) that provide such functionalities as penetration testing, incident response, cyber hunting, and risk and vulnerability assessment for programs—and integrated adaptive cyber defense (IACD) for the enterprise and beyond. Strategies for risk-adaptive management include:

- Changing the frequency of planned changes (e.g., resetting encryption keys, switching between operating systems or platforms, or changing the configuration of internal routers)
- Increasing security restrictions (e.g., requiring reauthentication periodically within a single session, two-factor authentication for requests from remote locations, or two-person control on specific actions, increasing privilege requirements based on changing criticality)
- Reallocating resources (e.g., reallocating processing, communications, or storage resources to enable graceful degradation and the repurposing of resources)
- Discarding or isolating suspected system elements (e.g., terminating a service or locking out a user account, diverting communications to a deception environment, or quarantining processing)

Strategies for implementing this design principle can be applied in conjunction with strategies for implementing [Control visibility and use](#) (dynamically changing privileges), [Contain and exclude behaviors](#) (disabling resources and dynamic isolation), [Layer defenses and partition resources](#) (dynamic partitioning), [Plan and manage diversity](#) (switching from one resource to an equivalent resource), and [Make resources location-versatile](#) (reconstituting resources).

To be *risk*-adaptive, the selection and application of a strategy should be based on situational awareness—that is, management decisions are based on indications of changes in adversary characteristics, characteristics of system elements, or patterns of operational use that change the risk posture of the system or the mission or business function it supports. Alternately, strategies can be applied unpredictably to address unknown risks.

D.5.2.11 Maximize Transience

Non-persistence is a cyber resiliency strategy to [Reduce attack surfaces](#) in the temporal dimension. Virtualization technologies, which simulate the hardware and/or software on which

2693 other software executes [[SP 800-125B](#)], enable processes, services, and applications to be
2694 transient. At the network layer, technologies for network virtualization, network functions
2695 virtualization, software-defined networking, and just-in-time connectivity can support non-
2696 persistence. Data virtualization provides a strategy for reducing persistent local data stores. As
2697 noted above, this principle is synergistic with [Make resources location-versatile](#). Since transient
2698 resources can be virtually isolated, this principle can also be used in conjunction with [Contain](#)
2699 [and exclude behaviors](#).

2700 Logical transient system elements (e.g., processes, files, connections) need to be expunged (i.e.,
2701 removed in such a way that no data remains on the shared resources).¹²⁴ If an executing process
2702 or service has been compromised by malicious software that changes its behavior or corrupts
2703 the data it offers to other system elements, expunging it—either by bringing it down or by
2704 moving it and deleting the prior instance—also mitigates the compromise. This can be done in
2705 response to suspicious behavior or be deliberately unpredictable.

2706 In addition, system elements can be made attritable and expendable, such as in the case of
2707 unmanned air systems. These physically transient system elements also need mechanisms for
2708 ensuring that no data is left behind.

2709 The instantiation of a transient resource depends on being able to [Determine ongoing](#)
2710 [trustworthiness](#) of the resources from which it is constructed. Support for such verification
2711 and/or validation can include gold copies of software and configuration data, policy data for
2712 network function virtualization, and data quality validation as part of data virtualization.

2713 **D.5.2.12 Determine Ongoing Trustworthiness**

2714 In the *Command and Control* and *Defense Evasion* phases of the cyber attack life cycle
2715 [[MITRE18](#)], an adversary can modify system components (e.g., modify software, replace
2716 legitimate software with malware), system data (e.g., modify configuration files, fabricate
2717 entries in an authorization database, fabricate or delete audit data), or mission or business data
2718 (e.g., deleting, changing, or inserting entries in a mission or business database; replacing user-
2719 created files with fabricated versions). These modifications enable the adversary to take actions
2720 in the *Impact* and *Persistence* phases of the cyber attack life cycle. Periodic or ongoing validation
2721 can detect the effects of adversary activities before they become too significant or irremediable.

2722 A variety of [Substantiated Integrity](#) mechanisms can be used to identify suspicious changes to
2723 properties or behavior. Some behaviors (e.g., the frequency with which a service makes
2724 requests, the latency between a request to it and its response, and the size of requests or
2725 responses it makes) can be verified or validated by other services. Other behaviors (e.g.,
2726 processor, memory, disk, or network) can be verified or validated by other system components
2727 (e.g., the operating system’s task manager). Note that making the behavior capable of being
2728 verified or validated can impede the use of unpredictability.

2729 This principle is strongly synergistic with [Manage resources \(risk-\) adaptively](#). Some changes can
2730 trigger the use of [Privilege Restriction](#) or [Analytic Monitoring](#) mechanisms. Other changes can
2731 trigger quarantine via [Segmentation](#). However, such mechanisms can add storage, processing,

¹²⁴ See [[SP 800-53](#)] controls SC-4 (Information in Shared System Resources) and MP-6 (Media Sanitization).

2732 and transmission overhead. Therefore, this structural principle is most effective in support of
2733 the [Focus on common critical assets](#) strategic principle.

2734 Ideally, any system element that cannot be determined to be trustworthy—initially via
2735 hardware and software assurance processes and subsequently via [Substantiated Integrity](#)—
2736 should be assumed to be compromised. However, in practice, that assumption is difficult to
2737 apply. This principle is consistent with the weaker assumption that some resources will be
2738 compromised and calls for mechanisms to detect and respond to evidence of compromise.

2739 Mechanisms to determine trustworthiness need to be applied in a coordinated manner, across
2740 architectural layers, among different types of system elements, and (if applicable) with insider
2741 threat controls.

2742 **D.5.2.13 Change or Disrupt the Attack Surface**

2743 Disruption of the attack surface can also lead an adversary to reveal its presence. A growing set
2744 of moving target defenses are intended to change or disrupt the attack surface of a system.
2745 Moving Target Defense (MTD) is an active area of research and development. MTD can be
2746 categorized in terms of the *layer* or level at which the defenses are applied (e.g., software,
2747 runtime environment, data, platform, and network). However, MTD can be applied at other
2748 layers. For example, when this design principle is used in conjunction with the [Make resources](#)
2749 [location-versatile](#) principle, MTD can also be applied at the physical or geographic levels. MTD is
2750 particularly well-suited to cloud architectures [[Shetty16](#)] where implementation is at the
2751 middleware level.

2752 MTD can also be categorized in terms of strategy: move, morph, or switch. Resources can be
2753 moved (e.g., execution of a service can be moved from one platform or virtual machine to
2754 another). This approach, which leverages the design principle of [Dynamic Positioning](#), can be
2755 used in conjunction with the [Make resources location-versatile](#) principle. The terms “cyber
2756 maneuver” and MTD are often reserved for morphing—that is, making specific changes to the
2757 properties of the data, runtime environment, software, platform, or network [[Okhravi13](#)] or by
2758 using configuration changes in conjunction with the techniques of [Diversity](#) and [Unpredictability](#)
2759 or randomization [[Jajodia11](#), [Jajodia12](#)] rather than including relocation or distribution. Data or
2760 software can be morphed using synthetic diversity; the behavior of system elements can be
2761 morphed via configuration or resource allocation changes. Morphing can also be part of a
2762 [Deception](#) strategy. Finally, switching can leverage diversity and distributed resources. Mission
2763 applications that rely on a supporting service can switch from one implementation of the service
2764 to another. Switching can also be used in conjunction with Deception, as when adversary
2765 interactions with the system are switched to a deception environment.

2766 This structural design principle supports the [Expect adversaries to evolve](#) strategic principle. It
2767 can also support the [Reduce attack surfaces](#) strategic principle. Alternately, the principle can
2768 support the [Assume compromised resources](#) principle. When [Unpredictability](#) is part of the way
2769 this principle is applied, it should be used in conjunction with the [Make the effects of deception](#)
2770 [and unpredictability user-transparent](#) structural principle.

2771 **D.5.2.14 Make Deception and Unpredictability Effects User-Transparent**

2772 Deception and unpredictability are intended to increase an adversary’s uncertainty about the
2773 system’s structure and behavior, what effects an adversary might be able to achieve, and what

2774 actions cyber defenders might take in response to suspected malicious cyber-related activities.
2775 [Heckman15] provides a detailed discussion of deception and its role in active cyber defense.
2776 Deception includes obfuscation, which increases the effort needed by the adversary and can
2777 hide mission activities long enough for the mission to complete without adversary disruption.
2778 Active deception can divert adversary activities, causing the adversary to waste resources and
2779 reveal TTPs, intent, and targeting.

2780 Unpredictability can apply to structure, characteristics, or behavior. Unpredictable structure
2781 (e.g., dynamically changing partitions or isolating components) undermines the adversary's
2782 reconnaissance efforts. Unpredictable characteristics (e.g., configurations, selection of an
2783 equivalent element from a diverse set) force the adversary to develop a broader range of TTPs.
2784 Unpredictable behavior (e.g., response latency) increases uncertainty about effects and whether
2785 system behavior indicates defender awareness of malicious cyber activities.

2786 Unpredictability and deception can be applied separately and synergistically. These two
2787 techniques can be highly effective against advanced adversaries. However, if implemented
2788 poorly, deception and unpredictability can also increase the uncertainty of end-users and
2789 administrators about how the system will behave. Such user and administrator confusion can
2790 reduce overall resilience, reliability, and security. This uncertainty can, in turn, make the
2791 detection of unauthorized or suspicious behavior more difficult. This design principle calls for a
2792 sound implementation, which makes system behaviors directed at the adversary transparent to
2793 end-users and system administrators.

2794

TAILOR DESIGN PRINCIPLES AND APPLY SELECTIVELY

Cyber resiliency design principles are used to help guide analysis and engineering decisions and to help stakeholders understand the rationale for those decisions. Therefore, design principles can be tailored in terms that are meaningful to the purpose and architecture of the *system-of-interest*. For example, the [Support agility and architect for adaptability](#) strategic design principle might be tailored for a microgrid that supplies and manages power for a campus as follows:

Design microgrid constituent systems in a modular way to accommodate technology and usage concepts, which change at different rates.

The design principle might not be directly applicable to an implantable medical device, but it can be applied to a system-of-systems of which the device is a constituent system element in conjunction with the security design principle of *secure evolvability*.

Descriptions of how structural design principles apply will reflect the underlying architecture of the system-of-interest. For example, how the [Make resources location-versatile](#) design principle applies to a workflow system might depend on how the enterprise architecture incorporates virtualization and cloud services as well as how it provides off-site backup. Alternatively, the description of how the same design principle applies to a satellite constellation might refer to satellite maneuverability.

2795 D.6 RELATIONSHIPS AMONG CYBER RESILIENCY CONSTRUCTS

2796 Sections D.1 through D.5 presented and described the cyber resiliency constructs of goals,
 2797 objectives, techniques, approaches, and design principles. [Table D-12](#) and [Table D-13](#) illustrate
 2798 that the mapping between the goals and objectives is many-to-many, as are the mappings
 2799 between techniques (including the approaches to implementing or applying techniques) and
 2800 objectives.

2801 **TABLE D-12: CYBER RESILIENCY OBJECTIVES SUPPORTING CYBER RESILIENCY GOALS**

| Goals Objectives | ANTICIPATE | WITHSTAND | RECOVER | ADAPT |
|-------------------------------|------------|-----------|---------|-------|
| PREVENT/AVOID | X | X | | |
| PREPARE | X | X | X | X |
| CONTINUE | | X | X | |
| CONSTRAIN | | X | X | |
| RECONSTITUTE | | | X | |
| UNDERSTAND | X | X | X | X |
| TRANSFORM | | | X | X |
| RE-ARCHITECT | | | X | X |

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TABLE D-13: TECHNIQUES AND IMPLEMENTATION APPROACHES TO ACHIEVE OBJECTIVES

| Objectives Techniques/Approaches | Prevent / Avoid | Prepare | Continue | Constrain | Reconstitute | Understand | Transform | Re-Architect |
|--|--------------------|---------|----------|-----------|--------------|------------|-----------|--------------|
| ADAPTIVE RESPONSE | X | X | X | X | X | X | | |
| Dynamic Reconfiguration | X | | X | X | X | X | | |
| Dynamic Resource Allocation | X | | X | X | X | | | |
| Adaptive Management | X | X | X | X | X | X | | |
| ANALYTIC MONITORING | | | X | X | X | X | | |
| Monitoring and Damage Assessment | | | X | X | X | X | | |
| Sensor Fusion and Analysis | | | | | | X | | |
| Forensic and Behavioral Analysis | | | | | | X | | |
| CONTEXTUAL AWARENESS | | X | X | | X | X | | |
| Dynamic Resource Awareness | | X | | | | X | | |
| Dynamic Threat Awareness | | | | | | X | | |

| Objectives | Prevent / Avoid | Prepare | Continue | Constrain | Reconstitute | Understand | Transform | Re-Architect |
|--|-----------------|---------|----------|-----------|--------------|------------|-----------|--------------|
| Techniques/Approaches | | | | | | | | |
| <u>Mission Dependency and Status Visualization</u> | | X | X | | X | X | | |
| COORDINATED PROTECTION | X | X | X | | X | X | X | X |
| <u>Calibrated Defense-in-Depth</u> | X | X | | | X | | | |
| <u>Consistency Analysis</u> | X | X | | | X | X | X | X |
| <u>Orchestration</u> | X | X | X | | X | X | X | X |
| <u>Self-Challenge</u> | | X | | | | X | | |
| DECEPTION | X | | | | | X | | |
| <u>Obfuscation</u> | X | | | | | | | |
| <u>Disinformation</u> | X | | | | | | | |
| <u>Misdirection</u> | X | | | | | X | | |
| <u>Tainting</u> | | | | | | X | | |
| DIVERSITY | X | X | X | X | | | | X |
| <u>Architectural Diversity</u> | | X | X | | | | | X |
| <u>Design Diversity</u> | | X | X | | | | | X |
| <u>Synthetic Diversity</u> | X | X | X | X | | | | |
| <u>Information Diversity</u> | | X | X | | | | | X |
| <u>Path Diversity</u> | | X | X | | | | | X |
| <u>Supply Chain Diversity</u> | | X | X | | | | | X |
| DYNAMIC POSITIONING | X | | X | X | X | X | | |
| <u>Functional Relocation of Sensors</u> | | | | | X | X | | |
| <u>Functional Relocation of Cyber Resources</u> | X | | X | X | | | | |
| <u>Asset Mobility</u> | X | | X | X | | | | |
| <u>Fragmentation</u> | X | | | | X | | | |
| <u>Distributed Functionality</u> | X | | | | X | | | |
| NON-PERSISTENCE | X | | | X | | | X | X |
| <u>Non-Persistent Information</u> | X | | | X | | | X | X |
| <u>Non-Persistent Services</u> | X | | | X | | | X | X |
| <u>Non-Persistent Connectivity</u> | X | | | X | | | X | X |
| PRIVILEGE RESTRICTION | X | | | X | X | | | |
| <u>Trust-Based Privilege Management</u> | X | | | X | | | | |

| Objectives Techniques/Approaches | Prevent / Avoid | Prepare | Continue | Constrain | Reconstitute | Understand | Transform | Re-Architect |
|---|--------------------|---------|----------|-----------|--------------|------------|-----------|--------------|
| <u>Attribute-Based Usage Restriction</u> | X | | | | X | | | |
| <u>Dynamic Privileges</u> | X | | | X | X | | | |
| REALIGNMENT | X | | | | | | X | X |
| <u>Purposing</u> | X | | | | | | | X |
| <u>Offloading</u> | | | | | | | X | X |
| <u>Restriction</u> | | | | | | | X | X |
| <u>Replacement</u> | | | | | | | X | X |
| <u>Specialization</u> | | | | | | | X | X |
| <u>Evolvability</u> | | | | | | | X | X |
| REDUNDANCY | X | X | X | | X | | X | X |
| <u>Protected Backup and Restore</u> | | X | X | | X | | | |
| <u>Surplus Capacity</u> | | X | X | | | | | |
| <u>Replication</u> | X | X | X | | | | X | X |
| SEGMENTATION | X | | | X | X | | | X |
| <u>Predefined Segmentation</u> | X | | | X | X | | | X |
| <u>Dynamic Segmentation and Isolation</u> | X | | | X | X | | | |
| SUBSTANTIATED INTEGRITY | | | X | X | X | X | | |
| <u>Integrity Checks</u> | | | X | X | X | X | | |
| <u>Provenance Tracking</u> | | | X | | X | X | | |
| <u>Behavior Validation</u> | | | X | X | X | X | | |
| UNPREDICTABILITY | X | | | X | | | | |
| <u>Temporal Unpredictability</u> | X | | | X | | | | |
| <u>Contextual Unpredictability</u> | X | | | X | | | | |

2805

2806 Section D.5 identifies cyber resiliency design principles. Strategic design principles support
 2807 achieving cyber resiliency objectives as shown in Table D-14, while structural design principles
 2808 provide guidance on how to apply cyber resiliency techniques as shown in Table D-15. Some
 2809 techniques are required by a design principle; these techniques are **bolded**. Other techniques
 2810 (not bolded) are typically used in conjunction with required techniques to apply the design
 2811 principle more effectively, depending on the type of system to which the principle is applied.

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TABLE D-14: STRATEGIC DESIGN PRINCIPLES AND CYBER RESILIENCY OBJECTIVES

| Objectives Strategic Design Principles | Prevent / Avoid | Prepare | Continue | Constrain | Reconstitute | Understand | Transform | Re-Architect |
|--|-----------------|---------|----------|-----------|--------------|------------|-----------|--------------|
| <u>FOCUS ON COMMON CRITICAL ASSETS.</u> | X | | X | | X | X | | X |
| <u>SUPPORT AGILITY AND ARCHITECT FOR ADAPTABILITY.</u> | | X | X | | X | | X | X |
| <u>REDUCE ATTACK SURFACES.</u> | X | | | X | | X | X | X |
| <u>ASSUME COMPROMISED RESOURCES.</u> | | X | X | X | X | X | X | X |
| <u>EXPECT ADVERSARIES TO EVOLVE.</u> | | X | | | | X | X | X |

2814

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TABLE D-15: STRUCTURAL DESIGN PRINCIPLES AND CYBER RESILIENCY TECHNIQUES

| STRUCTURAL DESIGN PRINCIPLE | RELATED TECHNIQUE |
|--|---|
| <u>LIMIT THE NEED FOR TRUST.</u> | Coordinated Protection, <u>Privilege Restriction</u> , <u>Realignment</u> , <u>Substantiated Integrity</u> |
| <u>CONTROL VISIBILITY AND USE.</u> | Deception, Non-Persistence, <u>Privilege Restriction</u> , <u>Segmentation</u> |
| <u>CONTAIN AND EXCLUDE BEHAVIORS.</u> | Analytic Monitoring, Diversity, Non-Persistence, <u>Privilege Restriction</u> , <u>Segmentation</u> , Substantiated Integrity |
| <u>LAYER DEFENSES AND PARTITION RESOURCES.</u> | Analytic Monitoring, <u>Coordinated Protection</u> , Diversity, Dynamic Positioning, Redundancy, <u>Segmentation</u> |
| <u>PLAN AND MANAGE DIVERSITY.</u> | Coordinated Protection, <u>Diversity</u> , Redundancy |
| <u>MAINTAIN REDUNDANCY.</u> | Coordinated Protection, <u>Diversity</u> , Realignment, <u>Redundancy</u> |
| <u>MAKE RESOURCES LOCATION-VERSATILE.</u> | Adaptive Response, Diversity, <u>Dynamic Positioning</u> , Non-Persistence, Redundancy, <u>Unpredictability</u> |
| <u>LEVERAGE HEALTH AND STATUS DATA.</u> | Analytic Monitoring, <u>Contextual Awareness</u> , Substantiated Integrity |
| <u>MAINTAIN SITUATIONAL AWARENESS.</u> | Analytic Monitoring, <u>Contextual Awareness</u> |
| <u>MANAGE RESOURCES (RISK-) ADAPTIVELY.</u> | <u>Adaptive Response</u> , Coordinated Protection, Deception, Dynamic Positioning, Non-Persistence, <u>Privilege Restriction</u> , <u>Realignment</u> , Redundancy, <u>Segmentation</u> , <u>Unpredictability</u> |
| <u>MAXIMIZE TRANSIENCE.</u> | Analytic Monitoring, Dynamic Positioning, <u>Non-Persistence</u> , Substantiated Integrity, <u>Unpredictability</u> |
| <u>DETERMINE ONGOING TRUSTWORTHINESS.</u> | Coordinated Protection, <u>Substantiated Integrity</u> |
| <u>CHANGE OR DISRUPT THE ATTACK SURFACE.</u> | Adaptive Response, Deception, Diversity, <u>Dynamic Positioning</u> , <u>Non-Persistence</u> , <u>Unpredictability</u> |

| STRUCTURAL DESIGN PRINCIPLE | RELATED TECHNIQUE |
|--|---|
| MAKE THE EFFECTS OF DECEPTION AND UNPREDICTABILITY USER-TRANSPARENT. | Adaptive Response , Coordinated Protection , Deception , Unpredictability |

2817

2818 D.7 APPLICATION OF CYBER RESILIENCY CONSTRUCTS

2819 Cyber resiliency is addressed in conjunction with the closely related concerns of system
 2820 resilience and security. Engineering analysis for cyber resiliency emphasizes the need to meet
 2821 system requirements and address stakeholder concerns in the face of the APT. Cyber resiliency
 2822 focuses on the capabilities used to ensure the accomplishment of organizational missions or
 2823 business functions, such as to continue minimum essential operations throughout an attack
 2824 after the adversary has established a presence in the system as opposed to capabilities to
 2825 harden the system and to keep the adversary out. The cyber resiliency goals of anticipate,
 2826 withstand, recover, and adapt are oriented toward organizational missions or business functions
 2827 and thus complement such security objectives as confidentiality, integrity, and availability that
 2828 apply to information and information systems [[SP 800-37](#)]. Similarly, the cyber resiliency
 2829 objectives complement the cybersecurity functions of identify, protect, detect, respond, and
 2830 recover that an organization can use to achieve specific cybersecurity outcomes [[NIST CSF](#)].

2831 Due to this complementarity, cyber resiliency can also be incorporated into existing security
 2832 activities and tasks described in the systems life cycle processes in [[SP 800-160 v1](#)]. No new
 2833 processes are needed, nor are any new activities or tasks needed for the existing processes.
 2834 Several phrases are integral to the statement and elaboration of the activities and tasks in the
 2835 systems security engineering processes in [[SP 800-160 v1](#)]. These include security aspects,
 2836 security objectives, security models, concept of security function, security criteria, security-
 2837 driven constraints, security requirements, and security relevance as applied to a variety of
 2838 terms. To overcome any potential confusion, the tailoring of statements and elaborations to
 2839 address cyber resiliency will frequently replace the term *security* with *security and cyber*
 2840 *resiliency*. Cyber resiliency offers new considerations for these existing processes, activities, and
 2841 tasks. However, given that the language in the processes is not specific to cyber resiliency, it
 2842 may not always be obvious how and where cyber resiliency might be injected into the
 2843 engineering processes. The experience and expertise of systems security engineers can guide
 2844 and inform the use of the cyber resiliency constructs described in this publication.

SECONDARY EFFECTS OF APPLYING CYBER RESILIENCY CONSTRUCTS

In addition to the first-order effects realized by organizations due to the application of individual cyber resiliency techniques (or combination of techniques) defined in this publication, there may also be beneficial second-order effects. For example, the “noise” (i.e., distracting information) created by organizations that implement the cyber resiliency techniques of [Diversity](#), [Deception](#), and [Unpredictability](#) can help improve their detection capabilities and potentially reveal the presence of adversaries. Second-order effects are beyond the scope of this publication.

2845

2846 APPENDIX E

2847 **CONTROLS SUPPORTING CYBER RESILIENCY**

2848 NIST SP 800-53 SECURITY CONTROLS RELATED TO CYBER RESILIENCY

2849 This appendix identifies controls¹²⁵ in [SP 800-53] that directly support cyber resiliency. The
2850 methodology for determining whether a control directly supports cyber resiliency is
2851 outlined below. One of the challenges is that many controls can be considered to provide
2852 cybersecurity as well as cyber resiliency. In addition, many security practices that might, in
2853 principle, be considered good cybersecurity practices are not widely employed. Therefore, in
2854 these cases, if the control satisfies the other screening questions, the control is included in the
2855 listing. For each control in [SP 800-53], the following questions were used to identify controls
2856 that support cyber resiliency.

- 2857 • Is the control *primarily* focused on helping the system achieve a level of confidentiality,
2858 integrity, or availability¹²⁶ in situations where threats, excluding APT, are considered? If so,
2859 the control supports conventional information security. The control may provide functional,
2860 architectural, governance, or procedural capabilities that establish a necessary foundation
2861 for cyber resiliency. However, the control does not support cyber resiliency as a primary
2862 consideration.
- 2863 • Is the control *primarily* focused on ensuring the continuity of operations against threats of
2864 natural disasters, infrastructure failures, or cascading failures in which software or human
2865 errors are implicated? If so, the control supports *organizational* or *operational resilience* in
2866 the face of conventional threats. The control may provide functional, architectural,
2867 governance, or procedural capabilities that establish a necessary foundation for cyber
2868 resiliency. However, it does not support cyber resiliency, per se.
- 2869 • Does the control map to one or more of the 14 cyber resiliency techniques? The techniques
2870 characterize ways to achieve one or more cyber resiliency objectives. For some controls,
2871 mapping to a technique or an approach is trivial. For example, the control SI-14 (Non-
2872 Persistence) maps to the cyber resiliency technique of [Non-Persistence](#) as the control and
2873 cyber resiliency technique share the same name and achieve the same outcome. In other
2874 instances, the mapping is relatively straightforward, although not quite as trivial. For
2875 example, SC-29 (Heterogeneity) is about the use of diverse information resources so it
2876 supports the cyber resiliency [Diversity](#) technique. In other instances, the mapping is not as
2877 straightforward, and the guidance listed below should be employed to help identify cyber
2878 resiliency controls.
- 2879 • Does the control map to one of the cyber resiliency approaches that support the 14 cyber
2880 resiliency techniques? For example, SC-30(4) (Concealment and Misdirection | Misleading
2881 Information) maps to the [Disinformation](#) approach of the [Deception](#) technique. Since the
2882 approaches provide a finer granularity than the techniques, this question provides a more

¹²⁵ For the remainder of this appendix, the term *control* includes both base controls (e.g., AC-6) and control enhancements (e.g., AC-6(1)).

¹²⁶ The control baselines in [SP 800-53B] are defined for levels of concern for confidentiality, integrity, and availability with respect to threats other than the advanced persistent threat.

- 2883 detailed analysis of the controls, and a control that maps to an approach is *likely* to be a
2884 resiliency control.
- 2885 Many of the controls in [SP 800-53] address other important types of safeguards that are not
2886 necessarily related to cyber resiliency. Controls of this type are generally *not* included in the set
2887 of controls that support cyber resiliency. These controls include:
- 2888 • **Policy controls (the -1 controls)**
2889 The -1 controls (the policy and procedure controls) do not directly map to cyber resiliency
2890 techniques or approaches. Only a policy control that is specifically written to address the
2891 APT should be identified as a cyber resiliency control.
 - 2892 • **Documentation controls**
2893 Like the policy controls, documentation controls generally do not satisfy the conditions
2894 listed above. A documentation control would have to be narrowly focused (e.g., document
2895 how to respond to the presence of the advanced persistent threat) for it to be considered a
2896 cyber resiliency control.
 - 2897 • **Environmental controls (e.g., A/C, heating, found in PE family)**
2898 Environmental controls do not satisfy the conditions listed above unless they are narrowly
2899 focused (e.g., controls that address intentional power surges).
 - 2900 • **Personnel security controls**
2901 Personnel security controls do not satisfy the conditions listed above.
 - 2902 • **Compliance controls (e.g., those checking to ensure that all patches are up to date)**
2903 Cyber resiliency focuses primarily on evolving and adapting rather than on compliance.
2904 Thus, unless a control is explicitly focused on ensuring that some specific (already
2905 established) cyber resiliency capability is implemented correctly and operating as intended,
2906 compliance controls are generally not considered part of cyber resiliency.
 - 2907 • **Vulnerability assessment controls**
2908 While adversaries take advantage of vulnerabilities, identifying such vulnerabilities is not the
2909 focus of cyber resiliency.
- 2910 Some control families are more likely to support cyber resiliency than others. The Contingency
2911 Planning (CP), Incident Response (IR), System and Communications Protection (SC), and System
2912 and Information Integrity (SI) families have a high percentage of controls that are cyber
2913 resiliency-oriented. However, controls that support cyber resiliency are not confined to these
2914 families, nor are all controls in these families automatically controls supporting cyber resiliency.
- 2915 After applying the above criteria, there may still be some ambiguity for some controls as to
2916 whether or not they are cyber resiliency in their focus. This is due in part to the overlap between
2917 aspects of cybersecurity and cyber resiliency. Delineation between the two is not easy to
2918 discern. To illustrate the distinction, it is useful to reference first principles.
- 2919 *Cyber resiliency is essentially about ensuring continued mission operations despite the fact that*
2920 *an adversary has established a foothold in the organization's systems and cyber infrastructure.*

- Controls that are largely focused on keeping the adversary out of systems and infrastructure are generally not resiliency controls. For example, identification and authentication controls such as IA-4 (Identifier Management) are generally not focused on combating an adversary after they have achieved a foothold in an organizational system. Similarly, physical access controls (e.g., PE-2, PE-4) are generally considered basic information security measures, not cyber resiliency measures.
- One area where there is likely to be some confusion is between Auditing and Analytic Monitoring. Controls that are focused on the correlation of collected information are more likely to be Analytic Monitoring-focused. Controls that are focused on storage capacity for audit trails, what information should be captured in an audit trail, or retention of the audit trail are more likely to fall into the Audit domain.
- In many instances, cyber resiliency capabilities are reflected in control enhancements instead of base controls. In those situations, [[SP 800-53](#)] requires that a parent control be selected if one or more of its control enhancements are selected. This means that for any cyber resiliency control enhancement selected, the associated base control is also selected and included in the security plan for the system.

[Table E-1](#) identifies the controls and control enhancements in [[SP 800-53](#)] that support cyber resiliency using the criteria outlined above. For each of the selected “cyber resiliency controls or control enhancements,” the table specifies the corresponding cyber resiliency technique and approach. In many instances, more than a single cyber resiliency technique or approach is provided because many of the controls and enhancements support more than one cyber resiliency technique or approach. If there are multiple corresponding cyber resiliency techniques, they are listed in a *prioritized* order where the technique with the strongest linkage is listed first. The table will be updated as new versions of [[SP 800-53](#)] are published.

TABLE E-1: NIST CONTROLS SUPPORTING CYBER RESILIENCY TECHNIQUES

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|----------------|--|---|
| ACCESS CONTROL | | |
| AC-2(6) | ACCOUNT MANAGEMENT DYNAMIC PRIVILEGE MANAGEMENT | Privilege Restriction [Dynamic Privileges] Adaptive Response [Dynamic Reconfiguration] |
| AC-2(8) | ACCOUNT MANAGEMENT DYNAMIC ACCOUNT MANAGEMENT | Adaptive Response [Dynamic Resource Allocation, Dynamic Reconfiguration, Adaptive Management] Privilege Restriction [Dynamic Privileges] |
| AC-2(12) | ACCOUNT MANAGEMENT ACCOUNT MONITORING FOR ATYPICAL USAGE | Analytic Monitoring [Monitoring and Damage Assessment] Substantiated Integrity [Behavior Validation] |
| AC-3(2) | ACCESS ENFORCEMENT DUAL AUTHORIZATION | Privilege Restriction [Trust-Based Privilege Management] |
| AC-3(11) | ACCESS ENFORCEMENT RESTRICT ACCESS TO SPECIFIC INFORMATION TYPES | Privilege Restriction [Attribute-Based Usage Restriction] |
| AC-3(12) | ACCESS ENFORCEMENT ASSERT AND ENFORCE APPLICATION ACCESS | Privilege Restriction [Attribute-Based Usage Restriction] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------|--|---|
| AC-3(13) | ACCESS ENFORCEMENT ATTRIBUTE-BASED ACCESS CONTROL | Privilege Restriction [Attribute-Based Usage Restriction] |
| AC-4(2) | INFORMATION FLOW ENFORCEMENT PROCESSING DOMAINS | Segmentation [Predefined Segmentation] |
| AC-4(3) | INFORMATION FLOW ENFORCEMENT DYNAMIC INFORMATION FLOW CONTROL | Adaptive Response [Dynamic Reconfiguration, Adaptive Management] |
| AC-4(8) | INFORMATION FLOW ENFORCEMENT SECURITY AND PRIVACY POLICY FILTERS | Substantiated Integrity [Integrity Checks] |
| AC-4(12) | INFORMATION FLOW ENFORCEMENT DATA TYPE IDENTIFIERS | Substantiated Integrity [Integrity Checks] |
| AC-4(17) | INFORMATION FLOW ENFORCEMENT DOMAIN AUTHENTICATION | Substantiated Integrity [Provenance Tracking] |
| AC-4(21) | INFORMATION FLOW ENFORCEMENT PHYSICAL OR LOGICAL SEPARATION OF INFORMATION FLOWS | Segmentation [Predefined Segmentation] |
| AC-4(27) | INFORMATION FLOW ENFORCEMENT REDUNDANT/INDEPENDENT FILTERING MECHANISMS | Diversity [Design Diversity] Redundancy [Replication] |
| AC-4(29) | INFORMATION FLOW ENFORCEMENT FILTER ORCHESTRATION ENGINES | Coordinated Protection [Orchestration] |
| AC-4(30) | INFORMATION FLOW ENFORCEMENT FILTER MECHANISMS USING MULTIPLE PROCESSES | Diversity [Design Diversity] Redundancy [Replication] |
| AC-6 | LEAST PRIVILEGE | Privilege Restriction [Attribute-Based Usage Restriction] |
| AC-6(1) | LEAST PRIVILEGE AUTHORIZE ACCESS TO SECURITY FUNCTIONS | Privilege Restriction [Attribute-Based Usage Restriction] |
| AC-6(2) | LEAST PRIVILEGE NON-PRIVILEGED ACCESS FOR NONSECURITY FUNCTIONS | Privilege Restriction [Trust-Based Privilege Management] Realignment [Purposing] |
| AC-6(3) | LEAST PRIVILEGE NETWORK ACCESS TO PRIVILEGED COMMANDS | Privilege Restriction [Trust-Based Privilege Management] |
| AC-6(4) | LEAST PRIVILEGE SEPARATE PROCESSING DOMAINS | Privilege Restriction [Trust-Based Privilege Management, Attribute-Based Usage Restriction] Segmentation [Predefined Segmentation] |
| AC-6(5) | LEAST PRIVILEGE PRIVILEGED ACCOUNTS | Privilege Restriction [Trust-Based Privilege Management] |
| AC-6(6) | LEAST PRIVILEGE PRIVILEGED ACCESS BY NON-ORGANIZATIONAL USERS | Privilege Restriction [Trust-Based Privilege Management] |
| AC-6(7) | LEAST PRIVILEGE REVIEW OF USER PRIVILEGES | Coordinated Protection [Consistency Analysis] Privilege Restriction [Trust-Based Privilege Management] |
| AC-6(8) | LEAST PRIVILEGE PRIVILEGE LEVELS FOR CODE EXECUTION | Privilege Restriction [Attribute-Based Usage Restriction, Dynamic Privileges] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|---------------------------------|---|---|
| AC-6(10) | LEAST PRIVILEGE PROHIBIT NON-PRIVILEGED USERS FROM EXECUTING PRIVILEGED FUNCTIONS | Privilege Restriction [Attribute-Based Usage Restriction, Trust-Based Privilege Management] |
| AC-7(4) | UNSUCCESSFUL LOGON ATTEMPTS USE OF ALTERNATE AUTHENTICATION FACTOR | Diversity [Path Diversity] |
| AC-12 | SESSION TERMINATION | Non-Persistence [Non-Persistent Services] |
| AC-23 | DATA MINING PROTECTION | Analytic Monitoring [Monitoring and Damage Assessment] Privilege Restriction [Trust-Based Privilege Management, Attribute-Based Usage Restriction, Dynamic Privileges] |
| AWARENESS AND TRAINING | | |
| AT-2(1) | AWARENESS TRAINING PRACTICAL EXERCISES | Contextual Awareness [Dynamic Threat Awareness] Coordinated Protection [Self-Challenge] |
| AT-2(3) | AWARENESS TRAINING SOCIAL ENGINEERING AND MINING | Contextual Awareness [Dynamic Threat Awareness] |
| AT-2(5) | AWARENESS TRAINING ADVANCED PERSISTENT THREAT | Contextual Awareness [Dynamic Threat Awareness] |
| AT-3(3) | ROLE-BASED TRAINING PRACTICAL EXERCISES | Contextual Awareness [Dynamic Threat Awareness] Coordinated Protection [Self-Challenge] |
| AUDIT AND ACCOUNTABILITY | | |
| AU-5(3) | RESPONSE TO AUDIT PROCESSING FAILURES CONFIGURABLE TRAFFIC VOLUME THRESHOLDS | Adaptive Response [Dynamic Resource Allocation, Adaptive Management] |
| AU-6 | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING | Adaptive Response [Adaptive Management] Analytic Monitoring [Monitoring and Damage Assessment] Substantiated Integrity [Behavior Validation] |
| AU-6(3) | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING CORRELATE AUDIT REPOSITORIES | Analytic Monitoring [Sensor Fusion and Analysis] |
| AU-6(5) | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING INTEGRATED ANALYSIS OF AUDIT RECORDS | Analytic Monitoring [Sensor Fusion and Analysis] |
| AU-6(6) | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING CORRELATION WITH PHYSICAL MONITORING | Analytic Monitoring [Sensor Fusion and Analysis] |
| AU-6(8) | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING FULL TEXT ANALYSIS OF PRIVILEGED COMMANDS | Analytic Monitoring [Monitoring and Damage Assessment] Segmentation [Predefined Segmentation] |
| AU-6(9) | AUDIT RECORD REVIEW, ANALYSIS, AND REPORTING CORRELATION WITH INFORMATION FROM NONTECHNICAL SOURCES | Analytic Monitoring [Sensor Fusion and Analysis] |
| AU-9(1) | PROTECTION OF AUDIT INFORMATION HARDWARE WRITE-ONCE MEDIA | Substantiated Integrity [Integrity Checks] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|--|--|---|
| AU-9(2) | PROTECTION OF AUDIT INFORMATION STORE ON SEPARATE PHYSICAL SYSTEMS AND COMPONENTS | Segmentation [Predefined Segmentation] |
| AU-9(3) | PROTECTION OF AUDIT INFORMATION CRYPTOGRAPHIC PROTECTION | Substantiated Integrity [Integrity Checks] |
| AU-9(5) | PROTECTION OF AUDIT INFORMATION DUAL AUTHORIZATION | Privilege Restriction [Trust-Based Privilege Management] |
| AU-9(6) | PROTECTION OF AUDIT INFORMATION READ-ONLY ACCESS | Privilege Restriction [Trust-Based Privilege Management, Attribute-Based Usage Restriction] Substantiated Integrity [Integrity Checks] |
| AU-9(7) | PROTECTION OF AUDIT INFORMATION STORE ON COMPONENT WITH DIFFERENT OPERATING SYSTEM | Diversity [Architectural Diversity] |
| AU-10(2) | NON-REPUDIATION VALIDATE BINDING OF INFORMATION PRODUCER IDENTITY | Substantiated Integrity [Provenance Tracking] |
| AU-13 | MONITORING FOR INFORMATION DISCLOSURE | Adaptive Response [Adaptive Management] Analytic Monitoring [Monitoring and Damage Assessment] |
| AU-13(3) | MONITORING FOR INFORMATION DISCLOSURE UNAUTHORIZED REPLICATION OF INFORMATION | Analytic Monitoring [Monitoring and Damage Assessment] |
| ASSESSMENT, AUTHORIZATION, AND MONITORING | | |
| CA-7(3) | CONTINUOUS MONITORING TREND ANALYSES | Contextual Awareness [Dynamic Resource Awareness, Dynamic Threat Awareness] |
| CA-7(5) | CONTINUOUS MONITORING CONSISTENCY ANALYSIS | Coordinated Protection [Consistency Analysis] |
| CA-7(6) | CONTINUOUS MONITORING AUTOMATION SUPPORT FOR MONITORING | Analytic Monitoring [Monitoring and Damage Assessment] |
| CA-8 | PENETRATION TESTING | Coordinated Protection [Self-Challenge] |
| CA-8(1) | PENETRATION TESTING INDEPENDENT PENETRATION TESTING AGENT OR TEAM | Coordinated Protection [Self-Challenge] |
| CA-8(2) | PENETRATION TESTING RED TEAM EXERCISES | Coordinated Protection [Self-Challenge] |
| CA-8(3) | PENETRATION TESTING FACILITY PENETRATION TESTING | Coordinated Protection [Self-Challenge] |
| CONFIGURATION MANAGEMENT | | |
| CM-2(7) | BASELINE CONFIGURATION CONFIGURE SYSTEMS AND COMPONENTS FOR HIGH-RISK AREAS | Analytic Monitoring [Monitoring and Damage Assessment, Forensic and Behavioral Analysis] Realignment [Restriction] |
| CM-4(1) | IMPACT ANALYSES SEPARATE TEST ENVIRONMENTS | Segmentation [Predefined Segmentation] |
| CM-5(3) | ACCESS RESTRICTIONS FOR CHANGE SIGNED COMPONENTS | Substantiated Integrity [Integrity Checks, Provenance Tracking] |
| CM-5(4) | ACCESS RESTRICTIONS FOR CHANGE DUAL AUTHORIZATION | Privilege Restriction [Trust-Based Privilege Management] |
| CM-5(5) | ACCESS RESTRICTIONS FOR CHANGE PRIVILEGE LIMITATION FOR PRODUCTION AND OPERATION | Privilege Restriction [Trust-Based Privilege Management] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-----------------------------|---|--|
| CM-5(6) | ACCESS RESTRICTIONS FOR CHANGE LIMIT LIBRARY PRIVILEGES | Privilege Restriction [Trust-Based Privilege Management] |
| CM-7(2) | LEAST FUNCTIONALITY PREVENT PROGRAM EXECUTION | Realignment [Restriction] |
| CM-7(4) | LEAST FUNCTIONALITY UNAUTHORIZED SOFTWARE | Realignment [Purposing] |
| CM-7(5) | LEAST FUNCTIONALITY AUTHORIZED SOFTWARE | Privilege Restriction [Trust-Based Privilege Management] Segmentation [Predefined Segmentation, Dynamic Segmentation and Isolation] |
| CM-7(6) | LEAST FUNCTIONALITY CONFINED ENVIRONMENTS WITH LIMITED PRIVILEGES | Realignment [Purposing] |
| CM-7(7) | LEAST FUNCTIONALITY CODE EXECUTION IN PROTECTED ENVIRONMENTS | Segmentation [Predefined Segmentation] |
| CM-8(3) | SYSTEM COMPONENT INVENTORY AUTOMATED UNAUTHORIZED COMPONENT DETECTION | Analytic Monitoring [Monitoring and Damage Assessment] |
| CM-14 | SIGNED COMPONENTS | Substantiated Integrity [Integrity Checks, Provenance Tracking] |
| CONTINGENCY PLANNING | | |
| CP-2(1) | CONTINGENCY PLAN COORDINATE WITH RELATED PLANS | Coordinated Protection [Consistency Analysis] |
| CP-2(5) | CONTINGENCY PLAN CONTINUE MISSIONS AND BUSINESS FUNCTIONS | Coordinated Protection [Orchestration] Adaptive Response [Dynamic Reconfiguration, Adaptive Management] |
| CP-2(8) | CONTINGENCY PLAN IDENTIFY CRITICAL ASSETS | Contextual Awareness [Mission Dependency and Status Visualization] |
| CP-4(5) | SELF-CHALLENGE | Coordinated Protection [Self-Challenge] |
| CP-8(3) | TELECOMMUNICATIONS SERVICES SEPARATION OF PRIMARY AND ALTERNATE PROVIDERS | Diversity [Architectural Diversity] |
| CP-9 | SYSTEM BACKUP | Redundancy [Protected Backup and Restore] |
| CP-9(1) | SYSTEM BACKUP TESTING FOR RELIABILITY AND INTEGRITY | Redundancy [Protected Backup and Restore] Substantiated Integrity [Integrity Checks] |
| CP-9(6) | SYSTEM BACKUP REDUNDANT SECONDARY SYSTEM | Redundancy [Replication] |
| CP-9(7) | SYSTEM BACKUP DUAL AUTHORIZATION | Privilege Restriction [Trust-Based Privilege Management] |
| CP-9(8) | SYSTEM BACKUP CRYPTOGRAPHIC PROTECTION | Deception [Obfuscation] Redundancy [Protected Backup and Restore] Substantiated Integrity [Integrity Checks] |
| CP-11 | ALTERNATE COMMUNICATIONS PROTOCOLS | Diversity [Architectural Diversity, Design Diversity] |
| CP-12 | SAFE MODE | Adaptive Response [Adaptive Management] |
| CP-13 | ALTERNATIVE SECURITY MECHANISMS | Diversity [Architectural Diversity, Design Diversity] Adaptive Response [Adaptive Management] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|--|---|--|
| IDENTIFICATION AND AUTHENTICATION | | |
| IA-2(6) | IDENTIFICATION AND AUTHENTICATION ACCESS TO ACCOUNTS – SEPARATE DEVICE | Diversity [Path Diversity] Coordinated Protection [Calibrated Defense-in-Depth, Orchestration] |
| IA-2(13) | IDENTIFICATION AND AUTHENTICATION OUT-OF-BAND AUTHENTICATION | Diversity [Path Diversity] Coordinated Protection [Calibrated Defense-in-Depth, Orchestration] Segmentation [Predefined Segmentation] |
| IA-3(1) | DEVICE IDENTIFICATION AND AUTHENTICATION CRYPTOGRAPHIC BIDIRECTIONAL AUTHENTICATION | Deception [Obfuscation] Substantiated Integrity [Integrity Checks] |
| IA-10 | ADAPTIVE AUTHENTICATION | Adaptive Response [Adaptive Management] Privilege Restriction [Dynamic Privileges] Coordinated Protection [Calibrated Defense-in-Depth] |
| INCIDENT RESPONSE | | |
| IR-4(2) | INCIDENT HANDLING DYNAMIC RECONFIGURATION | Adaptive Response [Dynamic Reconfiguration] Dynamic Positioning [Functional Relocation of Sensors] |
| IR-4(3) | INCIDENT HANDLING CONTINUITY OF OPERATIONS | Adaptive Response [Dynamic Reconfiguration, Adaptive Management] Coordinated Protection [Orchestration] |
| IR-4(4) | INCIDENT HANDLING INFORMATION CORRELATION | Coordinated Protection [Orchestration] Analytic Monitoring [Sensor Fusion and Analysis] Contextual Awareness [Dynamic Threat Awareness] |
| IR-4(9) | INCIDENT HANDLING DYNAMIC RESPONSE CAPABILITY | Adaptive Response [Dynamic Reconfiguration] |
| IR-4(10) | INCIDENT HANDLING SUPPLY CHAIN COORDINATION | Coordinated Protection [Orchestration] |
| IR-4(11) | INCIDENT HANDLING INTEGRATED INCIDENT RESPONSE TEAM | Adaptive Response [Dynamic Reconfiguration, Adaptive Management] Analytic Monitoring [Forensic and Behavioral Analysis] Coordinated Protection [Orchestration] |
| IR-4(12) | INCIDENT HANDLING MALICIOUS CODE AND FORENSIC ANALYSIS | Analytic Monitoring [Forensic and Behavioral Analysis] Segmentation [Predefined Segmentation] |
| IR-4(13) | INCIDENT HANDLING BEHAVIOR ANALYSIS | Analytic Monitoring [Monitoring and Damage Assessment] Substantiated Integrity [Behavior Validation] |
| IR-5 | INCIDENT MONITORING | Analytic Monitoring [Monitoring and Damage Assessment, Forensic and Behavioral Analysis] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|--|---|---|
| MAINTENANCE | | |
| MA-4(4) | NONLOCAL MAINTENANCE AUTHENTICATION AND SEPARATION OF MAINTENANCE SESSIONS | Segmentation [Predefined Segmentation] |
| PHYSICAL AND ENVIRONMENTAL PROTECTION | | |
| PE-3(5) | PHYSICAL ACCESS CONTROL TAMPER PROTECTION | Substantiated Integrity [Integrity Checks] |
| PE-6 | MONITORING PHYSICAL ACCESS | Analytic Monitoring [Monitoring and Damage Assessment] |
| PE-6(2) | MONITORING PHYSICAL ACCESS AUTOMATED INTRUSION RECOGNITION AND RESPONSES | Analytic Monitoring [Monitoring and Damage Assessment] Adaptive Response [Adaptive Management] Coordinated Protection [Orchestration] |
| PE-6(4) | MONITORING PHYSICAL ACCESS MONITORING PHYSICAL ACCESS TO SYSTEMS | Analytic Monitoring [Monitoring and Damage Assessment] Coordinated Protection [Calibrated Defense-in-Depth] |
| PE-9(1) | POWER EQUIPMENT AND CABLING REDUNDANT CABLING | Redundancy [Replication] |
| PE-11(1) | EMERGENCY POWER ALTERNATE POWER SUPPLY – MINIMAL OPERATIONAL CAPABILITY | Redundancy [Replication] |
| PE-11(2) | EMERGENCY POWER ALTERNATE POWER SUPPLY – SELF-CONTAINED | Redundancy [Replication] |
| PE-17 | ALTERNATE WORK SITE | Redundancy [Replication] |
| PLANNING | | |
| PL-8(1) | SECURITY AND PRIVACY ARCHITECTURE DEFENSE IN DEPTH | Coordinated Protection [Calibrated] |
| PL-8(2) | SECURITY AND PRIVACY ARCHITECTURE SUPPLIER DIVERSITY | Diversity [Supply Chain Diversity] |
| PROGRAM MANAGEMENT | | |
| PM-7(1) | ENTERPRISE ARCHITECTURE OFFLOADING | Realignment [Offloading] |
| PM-16 | THREAT AWARENESS PROGRAM | Contextual Awareness [Dynamic Threat Awareness] |
| PM-16(1) | THREAT AWARENESS PROGRAM AUTOMATED MEANS FOR SHARING THREAT INTELLIGENCE | Contextual Awareness [Dynamic Threat Awareness] |
| PM-30(1) | SUPPLY CHAIN RISK MANAGEMENT SUPPLIERS OF CRITICAL OR MISSION-ESSENTIAL ITEMS | Substantiated Integrity [Provenance Tracking] |
| PM-31 | CONTINUOUS MONITORING STRATEGY | Analytic Monitoring [Monitoring and Damage Assessment, Sensor Fusion and Analysis] |
| PM-32 | PURPOSING | Realignment [Purposing] |
| RISK ASSESSMENT | | |
| RA-3(2) | RISK ASSESSMENT USE OF ALL-SOURCE INTELLIGENCE | Contextual Awareness [Dynamic Threat Awareness] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|---------------------------------|--|--|
| RA-3(3) | RISK ASSESSMENT DYNAMIC THREAT AWARENESS | Contextual Awareness [Dynamic Threat Awareness] Adaptive Response [Adaptive Management] |
| RA-3(4) | RISK ASSESSMENT PREDICTIVE CYBER ANALYTICS | Contextual Awareness [Dynamic Threat Awareness] |
| RA-5(4) | VULNERABILITY MONITORING AND SCANNING DISCOVERABLE INFORMATION | Analytic Monitoring [Monitoring and Damage Assessment] |
| RA-5(5) | VULNERABILITY MONITORING AND SCANNING PRIVILEGED ACCESS | Analytic Monitoring [Monitoring and Damage Assessment] Privilege Restriction [Attribute-Based Usage Restriction] |
| RA-5(6) | VULNERABILITY MONITORING AND SCANNING AUTOMATED TREND ANALYSES | Analytic Monitoring [Sensor Fusion and Analysis] |
| RA-5(8) | VULNERABILITY MONITORING AND SCANNING REVIEW HISTORIC AUDIT LOGS | Analytic Monitoring [Sensor Fusion and Analysis] |
| RA-5(10) | VULNERABILITY MONITORING AND SCANNING CORRELATE SCANNING INFORMATION | Analytic Monitoring [Sensor Fusion and Analysis] |
| RA-9 | CRITICALITY ANALYSIS | Contextual Awareness [Mission Dependency and Status Visualization] Realignment [Offloading] |
| RA-10 | THREAT HUNTING | Analytic Monitoring [Monitoring and Damage Assessment] Contextual Awareness [Dynamic Threat Awareness] |
| SYSTEM AND SERVICES ACQUISITION | | |
| SA-3(2) | SYSTEM DEVELOPMENT LIFECYCLE USE OF LIVE OR OPERATIONAL DATA | Segmentation [Predefined Segmentation] |
| SA-8(2) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES LEAST COMMON MECHANISM | Realignment [Offloading, Restriction] |
| SA-8(3) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES MODULARITY AND LAYERING | Coordinated Protection [Calibrated Defense-in-Depth] Realignment [Evolvability, Specialization] Segmentation [Predefined Segmentation] |
| SA-8(4) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES PARTIALLY ORDERED DEPENDENCIES | Coordinated Protection [Consistency Analysis] |
| SA-8(6) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES MINIMIZED SHARING | Realignment [Purposing, Restriction] Segmentation [Predefined Segmentation] |
| SA-8(7) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES REDUCED COMPLEXITY | Realignment [Purposing, Specialization] |
| SA-8(8) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES SECURE EVOLVABILITY | Coordinated Protection [Orchestration] Realignment [Evolvability] |
| SA-8(13) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES MINIMIZED SECURITY ELEMENTS | Realignment [Purposing, Restriction] |
| SA-8(15) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES PREDICATE PERMISSION | Privilege Restriction [Trust-Based Privilege Management, Attribute-Based Usage Restriction] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|---|---|--|
| SA-8(16) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES SELF-RELIANT TRUSTWORTHINESS | Adaptive Response [Adaptive Management] Segmentation [Dynamic Segmentation and Isolation] Substantiated Integrity [Integrity Checks] |
| SA-8(17) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES SECURE DISTRIBUTED COMPOSITION | Dynamic Positioning [Distributed Functionality] |
| SA-8(18) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES TRUSTED COMMUNICATIONS CHANNELS | Privilege Restriction [Attribute-Based Usage Restriction] |
| SA-8(19) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES CONTINUOUS PROTECTION | Redundancy [Protected Backup and Restore] Substantiated Integrity [Integrity Checks] |
| SA-8(31) | SECURITY AND PRIVACY ENGINEERING PRINCIPLES SECURE SYSTEM MODIFICATION | Realignment [Evolvability] |
| SA-9(7) | EXTERNAL SYSTEM SERVICES ORGANIZATION-CONTROLLED INTEGRITY CHECKING | Substantiated Integrity [Integrity Checks] |
| SA-11(2) | DEVELOPER TESTING AND EVALUATION THREAT MODELING AND VULNERABILITY ANALYSIS | Contextual Awareness [Dynamic Threat Awareness] |
| SA-11(5) | DEVELOPER TESTING AND EVALUATION PENETRATION TESTING | Coordinated Protection [Self-Challenge] |
| SA-11(6) | DEVELOPER TESTING AND EVALUATION ATTACK SURFACE REVIEWS | Realignment [Replacement] |
| SA-15(5) | DEVELOPMENT PROCESS, STANDARDS, AND TOOLS ATTACK SURFACE REDUCTION | Realignment [Replacement] |
| SA-17(6) | DEVELOPER SECURITY ARCHITECTURE AND DESIGN STRUCTURE FOR TESTING | Realignment [Evolvability] |
| SA-17(8) | DEVELOPER SECURITY ARCHITECTURE AND DESIGN ORCHESTRATION | Coordinated Protection [Orchestration] |
| SA-17(9) | DEVELOPER SECURITY ARCHITECTURE AND DESIGN DESIGN DIVERSITY | Diversity [Design Diversity] |
| SA-20 | CUSTOMIZED DEVELOPMENT OF CRITICAL COMPONENTS | Realignment [Specialization] |
| SA-23 | SPECIALIZATION | Realignment [Specialization] |
| SYSTEM AND COMMUNICATIONS PROTECTION | | |
| SC-2 | SEPARATION OF SYSTEM AND USER FUNCTIONALITY | Segmentation [Predefined Segmentation] |
| SC-2(1) | SEPARATION OF SYSTEM AND USER FUNCTIONALITY INTERFACES FOR NON-PRIVILEGED USERS | Segmentation [Predefined Segmentation] |
| SC-3 | SECURITY FUNCTION ISOLATION | Segmentation [Predefined Segmentation] |
| SC-3(1) | SECURITY FUNCTION ISOLATION HARDWARE SEPARATION | Segmentation [Predefined Segmentation] |
| SC-3(2) | SECURITY FUNCTION ISOLATION ACCESS AND FLOW CONTROL FUNCTIONS | Segmentation [Predefined Segmentation] |
| SC-3(3) | SECURITY FUNCTION ISOLATION MINIMIZE NONSECURITY FUNCTIONALITY | Realignment [Restriction] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------|---|--|
| SC-3(5) | SECURITY FUNCTION ISOLATION LAYERED STRUCTURES | Coordinated Protection [Orchestration] Segmentation [Predefined Segmentation] Realignment [Offloading] |
| SC-5(2) | DENIAL OF SERVICE PROTECTION CAPACITY, BANDWIDTH, AND REDUNDANCY | Adaptive Response [Dynamic Resource Allocation] Redundancy [Surplus Capacity] |
| SC-5(3) | DENIAL OF SERVICE PROTECTION DETECTION AND MONITORING | Analytic Monitoring [Monitoring and Damage Assessment] |
| SC-7 | BOUNDARY PROTECTION | Segmentation [Predefined Segmentation] |
| SC-7(10) | BOUNDARY PROTECTION PREVENT EXFILTRATION | Analytic Monitoring [Monitoring and Damage Assessment] Non-Persistence [Non-Persistent Information, Non-Persistent Connectivity] Coordinated Protection [Self-Challenge] |
| SC-7(11) | BOUNDARY PROTECTION RESTRICT INCOMING COMMUNICATIONS TRAFFIC | Substantiated Integrity [Provenance Tracking] |
| SC-7(13) | BOUNDARY PROTECTION ISOLATION OF SECURITY TOOLS, MECHANISMS, AND SUPPORT COMPONENTS | Segmentation [Predefined Segmentation] |
| SC-7(15) | BOUNDARY PROTECTION NETWORK PRIVILEGE ACCESSES | Realignment [Offloading] Segmentation [Predefined Segmentation] Privilege Restriction [Trust-Based Privileged Management] |
| SC-7(16) | BOUNDARY PROTECTION PREVENT DISCOVERY OF SYSTEM COMPONENTS | Deception [Obfuscation] Dynamic Positioning [Functional Relocation of Cyber Resources] |
| SC-7(20) | BOUNDARY PROTECTION DYNAMIC ISOLATION AND SEGREGATION | Segmentation [Dynamic Segmentation and Isolation] Adaptive Response [Dynamic Reconfiguration] |
| SC-7(21) | BOUNDARY PROTECTION ISOLATION OF SYSTEM COMPONENTS | Segmentation [Predefined Segmentation] |
| SC-7(22) | BOUNDARY PROTECTION SEPARATE SUBNETS FOR CONNECTING TO DIFFERENT SECURITY DOMAINS | Segmentation [Predefined Segmentation] |
| SC-7(29) | BOUNDARY PROTECTION SEPARATE SUBNETS TO ISOLATE FUNCTIONS | Segmentation [Predefined Segmentation] |
| SC-8(1) | TRANSMISSION CONFIDENTIALITY AND INTEGRITY CRYPTOGRAPHIC PROTECTION | Substantiated Integrity [Integrity Checks] |
| SC-8(4) | TRANSMISSION CONFIDENTIALITY AND INTEGRITY CONCEAL OR RANDOMIZE COMMUNICATIONS | Deception [Obfuscation] Unpredictability [Contextual Unpredictability] |
| SC-8(5) | TRANSMISSION CONFIDENTIALITY AND INTEGRITY PROTECTED DISTRIBUTION SYSTEM | Substantiated Integrity [Integrity Checks] Segmentation [Predefined Segmentation] |
| SC-10 | NETWORK DISCONNECT | Non-Persistence [Non-Persistent Connectivity] |
| SC-11 | TRUSTED PATH | Segmentation [Predefined Segmentation] Substantiated Integrity [Provenance Tracking] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------|--|--|
| SC-15(1) | COLLABORATIVE COMPUTING DEVICES PHYSICAL OR LOGICAL DISCONNECT | Non-Persistence [Non-Persistent Connectivity] |
| SC-16(1) | TRANSMISSION OF SECURITY AND PRIVACY ATTRIBUTES INTEGRITY VERIFICATION | Substantiated Integrity [Integrity Checks] |
| SC-16(3) | TRANSMISSION OF SECURITY AND PRIVACY ATTRIBUTES CRYPTOGRAPHIC BINDING | Substantiated Integrity [Integrity Checks] |
| SC-18(5) | MOBILE CODE ALLOW EXECUTION ONLY IN CONFINED ENVIRONMENTS | Segmentation [Dynamic Segmentation and Isolation] |
| SC-22 | ARCHITECTURE AND PROVISIONING FOR NAME/ADDRESS RESOLUTION SERVICE | Redundancy [Replication] |
| SC-23(3) | SESSION AUTHENTICITY UNIQUE SYSTEM-GENERATED SESSION IDENTIFIERS | Non-Persistence [Non-Persistent Information] Unpredictability [Temporal Unpredictability] |
| SC-25 | THIN NODES | Realignment [Offloading, Restriction] Non-Persistence [Non-Persistent Services, Non-Persistent Information] |
| SC-26 | DECOYS | Deception [Misdirection] Analytic Monitoring [Monitoring and Damage Assessment, Forensic and Behavioral Analysis] |
| SC-28(1) | PROTECTION OF INFORMATION AT REST CRYPTOGRAPHIC PROTECTION | Deception [Obfuscation] Substantiated Integrity [Integrity Checks] |
| SC-29 | HETEROGENEITY | Diversity [Architectural Diversity] |
| SC-29(1) | HETEROGENEITY VIRTUALIZATION TECHNIQUES | Diversity [Architectural Diversity] Non-Persistence [Non-Persistent Services] |
| SC-30 | CONCEALMENT AND MISDIRECTION | Deception [Obfuscation, Misdirection] |
| SC-30(2) | CONCEALMENT AND MISDIRECTION RANDOMNESS | Unpredictability [Temporal Unpredictability, Contextual Unpredictability] |
| SC-30(3) | CONCEALMENT AND MISDIRECTION CHANGE PROCESSING AND STORAGE LOCATIONS | Dynamic Positioning [Asset Mobility, Functional Relocation of Cyber Resources] Unpredictability [Temporal Unpredictability] |
| SC-30(4) | CONCEALMENT AND MISDIRECTION MISLEADING INFORMATION | Deception [Disinformation] |
| SC-30(5) | CONCEALMENT AND MISDIRECTION CONCEALMENT OF SYSTEM COMPONENTS | Deception [Obfuscation] |
| SC-32 | SYSTEM PARTITIONING | Segmentation [Predefined Segmentation] |
| SC-32(1) | SYSTEM PARTITIONING SEPARATE PHYSICAL DOMAINS FOR PRIVILEGED FUNCTIONS | Segmentation [Predefined Segmentation, Dynamic Segmentation and Isolation] |
| SC-34 | NON-MODIFIABLE EXECUTABLE PROGRAMS | Substantiated Integrity [Integrity Checks] |
| SC-34(1) | NON-MODIFIABLE EXECUTABLE PROGRAMS NO WRITABLE STORAGE | Non-Persistence [Non-Persistent Information] |
| SC-34(2) | NON-MODIFIABLE EXECUTABLE PROGRAMS INTEGRITY PROTECTION ON READ-ONLY MEDIA | Substantiated Integrity [Integrity Checks] |
| SC-35 | EXTERNAL MALICIOUS CODE IDENTIFICATION | Analytic Monitoring [Monitoring and Damage Assessment, Forensic and Behavioral Analysis] Deception [Misdirection] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|---|---|--|
| | | Segmentation [Dynamic Segmentation and Isolation] |
| SC-36 | DISTRIBUTED PROCESSING AND STORAGE | Dynamic Positioning [Distributed Functionality, Functional Relocation of Cyber Resources] Redundancy [Replication] |
| SC-36(1) | DISTRIBUTED PROCESSING AND STORAGE POLLING TECHNIQUES | Substantiated Integrity [Behavior Validation] |
| SC-36(2) | DISTRIBUTED PROCESSING AND STORAGE SYNCHRONIZATION | Redundancy [Replication] Coordinated Protection [Orchestration] |
| SC-37 | OUT-OF-BAND CHANNELS | Diversity [Path Diversity] |
| SC-39 | PROCESS ISOLATION | Segmentation [Predefined Segmentation, Dynamic Segmentation and Isolation] |
| SC-39(1) | PROCESS ISOLATION HARDWARE SEPARATION | Segmentation [Predefined Segmentation, Dynamic Segmentation and Isolation] |
| SC-39(2) | PROCESS ISOLATION SEPARATION EXECUTION DOMAINS PER THREAD | Segmentation [Predefined Segmentation, Dynamic Segmentation and Isolation] |
| SC-40(2) | WIRELESS LINK PROTECTION REDUCE DETECTION POTENTIAL | Deception [Obfuscation] |
| SC-40(3) | WIRELESS LINK PROTECTION IMITATIVE OR MANIPULATIVE COMMUNICATIONS DECEPTION | Deception [Obfuscation] Unpredictability [Temporal Unpredictability, Contextual Unpredictability] |
| SC-44 | DETONATION CHAMBERS | Segmentation [Predefined Segmentation] Analytic Monitoring [Forensic and Behavioral Analysis] Deception [Misdirection] |
| SC-46 | CROSS-DOMAIN POLICY ENFORCEMENT | Segmentation [Predefined Segmentation] |
| SC-47 | ALTERNATE COMMUNICATION PATHS | Diversity [Path Diversity] |
| SC-48 | SENSOR RELOCATION | Dynamic Positioning [Functional Relocation of Sensors] |
| SC-48(1) | SENSOR RELOCATION DYNAMIC RELOCATION OF SENSORS OR MONITORING CAPABILITIES | Dynamic Positioning [Functional Relocation of Sensors] |
| SC-49 | HARDWARE-ENFORCED SEPARATION AND POLICY ENFORCEMENT | Segmentation [Predefined Segmentation] |
| SC-50 | SOFTWARE-ENFORCED SEPARATION AND POLICY ENFORCEMENT | Segmentation [Predefined Segmentation] |
| SC-51 | NON-MODIFIABLE EXECUTABLE PROGRAMS HARDWARE-BASED PROTECTION | Substantiated Integrity [Integrity Checks] |
| SYSTEM AND INFORMATION INTEGRITY | | |
| SI-3(10) | MALICIOUS CODE PROTECTION MALICIOUS CODE ANALYSIS | Analytic Monitoring [Forensic and Behavioral Analysis] |
| SI-4(1) | SYSTEM MONITORING SYSTEM-WIDE INTRUSION DETECTION SYSTEM | Analytic Monitoring [Sensor Fusion and Analysis] Contextual Awareness [Mission Dependency and Status Visualization] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------|--|---|
| SI-4(2) | SYSTEM MONITORING AUTOMATED TOOLS AND MECHANISMS FOR REAL-TIME ANALYSIS | Analytic Monitoring [Monitoring and Damage Assessment] Contextual Awareness [Mission Dependency and Status Visualization] Substantiated Integrity [Behavior Validation] |
| SI-4(3) | SYSTEM MONITORING AUTOMATED TOOL AND MECHANISM INTEGRATION | Analytic Monitoring [Sensor Fusion and Analysis] Adaptive Response [Adaptive Management] |
| SI-4(4) | SYSTEM MONITORING INBOUND AND OUTBOUND COMMUNICATIONS TRAFFIC | Analytic Monitoring [Monitoring and Damage Assessment] Substantiated Integrity [Behavior Validation] |
| SI-4(7) | SYSTEM MONITORING AUTOMATED RESPONSE TO SUSPICIOUS EVENTS | Analytic Monitoring [Monitoring and Damage Assessment] Adaptive Response [Adaptive Management] |
| SI-4(10) | SYSTEM MONITORING VISIBILITY OF ENCRYPTED COMMUNICATIONS | Analytic Monitoring [Monitoring and Damage Assessment] |
| SI-4(11) | SYSTEM MONITORING ANALYZE COMMUNICATIONS TRAFFIC ANOMALIES | Analytic Monitoring [Monitoring and Damage Assessment] |
| SI-4(13) | SYSTEM MONITORING ANALYZE TRAFFIC AND EVENT PATTERNS | Analytic Monitoring [Monitoring and Damage Assessment] Substantiated Integrity [Behavior Validation] |
| SI-4(16) | SYSTEM MONITORING CORRELATE MONITORING INFORMATION | Analytic Monitoring [Sensor Fusion and Analysis] Contextual Awareness [Dynamic Resource Awareness] |
| SI-4(17) | SYSTEM MONITORING INTEGRATED SITUATIONAL AWARENESS | Analytic Monitoring [Sensor Fusion and Analysis] Contextual Awareness [Dynamic Resource Awareness] |
| SI-4(18) | SYSTEM MONITORING ANALYZE TRAFFIC AND COVERT EXFILTRATION | Analytic Monitoring [Monitoring and Damage Assessment] |
| SI-4(24) | SYSTEM MONITORING INDICATORS OF COMPROMISE | Analytic Monitoring [Monitoring and Damage Assessment, Sensor Fusion and Analysis] |
| SI-4(25) | SYSTEM MONITORING OPTIMIZE NETWORK TRAFFIC ANALYSIS | Analytic Monitoring [Sensor Fusion and Analysis] |
| SI-6 | SECURITY AND PRIVACY FUNCTION VERIFICATION | Substantiated Integrity [Integrity Checks] |
| SI-7 | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY | Substantiated Integrity [Integrity Checks] |
| SI-7(1) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY INTEGRITY CHECKS | Substantiated Integrity [Integrity Checks] |
| SI-7(5) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY AUTOMATED RESPONSE TO INTEGRITY VIOLATIONS | Substantiated Integrity [Integrity Checks] Adaptive Response [Adaptive Management] |
| SI-7(6) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY CRYPTOGRAPHIC PROTECTION | Substantiated Integrity [Integrity Checks] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------------------------------|---|--|
| SI-7(7) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY INTEGRATION OF DETECTION AND RESPONSE | Substantiated Integrity [Integrity Checks] Analytic Monitoring [Monitoring and Damage Assessment] |
| SI-7(9) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY VERIFY BOOT PROCESS | Substantiated Integrity [Integrity Checks] |
| SI-7(10) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY PROTECTION OF BOOT FIRMWARE | Substantiated Integrity [Integrity Checks] |
| SI-7(12) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY INTEGRITY VERIFICATION | Substantiated Integrity [Integrity Checks] |
| SI-7(15) | SOFTWARE, FIRMWARE, AND INFORMATION INTEGRITY CODE AUTHENTICATION | Substantiated Integrity [Provenance Tracking] |
| SI-10(3) | INFORMATION INPUT VALIDATION PREDICTABLE BEHAVIOR | Substantiated Integrity [Behavior Validation] |
| SI-10(5) | INFORMATION INPUT VALIDATION RESTRICT INPUTS TO TRUSTED SOURCES AND APPROVED FORMATS | Substantiated Integrity [Provenance Tracking] |
| SI-14 | NON-PERSISTENCE | Non-Persistence [Non-Persistent Services] |
| SI-14(1) | NON-PERSISTENCE REFRESH FROM TRUSTED SOURCES | Non-Persistence [Non-Persistent Services, Non-Persistent Information] Substantiated Integrity [Provenance Tracking] |
| SI-14(2) | NON-PERSISTENCE NON-PERSISTENT INFORMATION | Non-Persistence [Non-Persistent Information] |
| SI-14(3) | NON-PERSISTENCE NON-PERSISTENT CONNECTIVITY | Non-Persistence [Non-Persistent Connectivity] |
| SI-15 | INFORMATION OUTPUT FILTERING | Substantiated Integrity [Integrity Checks] |
| SI-16 | MEMORY PROTECTION | Diversity [Synthetic Diversity] Unpredictability [Temporal Unpredictability] |
| SI-19(4) | DE-IDENTIFICATION REMOVAL, MASKING, ENCRYPTION, HASHING, OR REPLACEMENT OF DIRECT IDENTIFIERS | Deception [Obfuscation] |
| SI-19(6) | DE-IDENTIFICATION DIFFERENTIAL PRIVACY | Deception [Obfuscation] Uncertainty [Contextual Uncertainty] |
| SI-19(8) | DE-IDENTIFICATION MOTIVATED INTRUDER | Coordinated Protection [Self-Challenge] |
| SI-20 | TAINTING | Deception [Tainting] |
| SI-21 | INFORMATION REFRESH | Non-Persistence [Non-Persistent Information] |
| SI-22 | INFORMATION DIVERSITY | Diversity [Information Diversity] |
| SI-23 | INFORMATION FRAGMENTATION | Dynamic Positioning [Fragmentation] |
| SUPPLY CHAIN RISK MANAGEMENT | | |
| SR-3(1) | SUPPLY CHAIN CONTROLS AND PROCESSES DIVERSE SUPPLY CHAIN | Diversity [Supply Chain Diversity] |
| SR-3(2) | SUPPLY CHAIN CONTROLS AND PROCESSES LIMITATION OF HARM | Diversity [Supply Chain Diversity] Deception [Obfuscation] |
| SR-4 | PROVENANCE | Substantiated Integrity [Provenance Tracking] |

| CONTROL NO. | CONTROL NAME | RESILIENCY TECHNIQUE [APPROACHES] |
|-------------|--|--|
| SR-4(1) | PROVENANCE IDENTITY | Substantiated Integrity [Provenance Tracking] |
| SR-4(2) | PROVENANCE TRACK AND TRACE | Substantiated Integrity [Provenance Tracking] |
| SR-4(3) | PROVENANCE VALIDATE AS GENUINE AND NOT ALTERED | Substantiated Integrity [Integrity Checks, Provenance Tracking] |
| SR-4(4) | PROVENANCE SUPPLY CHAIN INTEGRITY – PEDIGREE | Substantiated Integrity [Provenance Tracking] |
| SR-5 | ACQUISITION STRATEGIES, TOOLS, AND METHODS | Substantiated Integrity [Integrity Checks, Provenance Tracking] Deception [Obfuscation] |
| SR-5(1) | ACQUISITION STRATEGIES, TOOLS, AND METHODS ADEQUATE SUPPLY | Redundancy [Replication] Diversity [Supply Chain Diversity] |
| SR-6(1) | SUPPLIER ASSESSMENTS AND REVIEWS TESTING AND ANALYSIS | Coordinated Protection [Self-Challenge] Analytic Monitoring [Monitoring and Damage Assessment] |
| SR-7 | SUPPLY CHAIN OPERATIONS SECURITY | Deception [Obfuscation, Disinformation, Self-Challenge] |
| SR-9 | TAMPER RESISTANCE AND DETECTION | Substantiated Integrity [Integrity Checks] |
| SR-9(1) | TAMPER RESISTANCE AND DETECTION MULTIPLE STAGES OF SYSTEM DEVELOPMENT LIFE CYCLE | Substantiated Integrity [Integrity Checks] Deception [Obfuscation] |
| SR-10 | INSPECTION OF SYSTEMS OR COMPONENTS | Substantiated Integrity [Integrity Checks] Analytic Monitoring [Monitoring and Damage Assessment, Forensic and Behavioral Analysis] |
| SR-11 | COMPONENT AUTHENTICITY | Substantiated Integrity [Integrity Checks, Provenance Tracking] |
| SR-11(3) | COMPONENT AUTHENTICITY ANTI-COUNTERFEIT SCANNING | Substantiated Integrity [Integrity Checks] |

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2947 APPENDIX F**2948 ADVERSARY-ORIENTED ANALYSIS****2949 APPROACHES FOR TAKING ADVERSARIAL ACTIVITIES INTO CONSIDERATION**

2950 This appendix supports an adversary-oriented analysis of a system and applications of cyber
2951 resiliency, as discussed in [Section 3.1.7](#), [Section 3.2.3.2](#), and [Section 3.2.4.3](#). [Section F.1](#)
2952 provides a vocabulary to describe the current or potential effects that a set of mitigations
2953 (i.e., risk-reducing actions or decisions, such as the application of cyber resiliency design
2954 principles, techniques, implementation approaches, requirements, controls, technologies, or
2955 solutions) could have on threat events, classes of threat events, or threat scenarios.¹²⁷ Each
2956 intended effect is characterized in terms of its potential impact on risk and the expected
2957 changes in adversary behavior. [Section F.2](#) presents the results of an analysis of the potential
2958 effects of mitigations that apply cyber resiliency approaches and controls on adversary TTPs
2959 using ATT&CK® for Enterprise.

2960 F.1 POTENTIAL EFFECTS ON THREAT EVENTS

2961 Cyber resiliency solutions are relevant only if they have some effect on risk, specifically by
2962 reducing the likelihood of the occurrence of threat events,¹²⁸ the ability of threat events to
2963 cause harm, and the extent of that harm.¹²⁹ The types of analysis of system architectures,
2964 designs, implementations, and operations that are indicated for cyber resiliency can include
2965 consideration of what effects alternatives could have on the threat events that are part of threat
2966 scenarios of concern to stakeholders.

2967 From the perspective of protecting a system against adversarial threats, five high-level, desired
2968 effects on the adversary can be identified: *redirect*, *preclude*, *impede*, *limit*, and *expose*. These
2969 effects are useful for discussion but are often too general to facilitate the definition of specific
2970 measures of effectiveness. Therefore, more specific classes of effects are defined:

- 2971 • Deter, divert, and deceive in support of **redirect**
- 2972 • Expunge, preempt, and negate in support of **preclude**
- 2973 • Contain, degrade, delay, and exert in support of **impede**
- 2974 • Shorten and reduce in support of **limit**
- 2975 • Detect, reveal, and scrutinize in support of **expose**

¹²⁷ While this appendix focuses on potential effects on adversary actions, most of the vocabulary applies to threat events caused by the full range of possible threat sources identified in [\[SP 800-30\]](#).

¹²⁸ The term *threat event* refers to an event or situation that has the potential to cause undesirable consequences or impacts. Threat events can be caused by either adversarial or non-adversarial threat sources. However, the emphasis in this section is on the effect on adversarial threats and, specifically, on the APT for which threat events can be identified with adversary activities.

¹²⁹ While many risk models are potentially valid and useful, three elements (or risk factors) are common across most models: (1) the *likelihood of occurrence* (i.e., the likelihood that a threat event or a threat scenario consisting of a set of interdependent events will occur or be initiated by an adversary), (2) the *likelihood of impact* (i.e., the likelihood that a threat event or scenario will result in an impact given vulnerabilities, weaknesses, and predisposing conditions), and (3) the *level of the impact* [\[SP 800-30\]](#). In general use, “mitigation” relates to impact reduction. However, when applied to a threat event, mitigation can relate to the reduction of any of these risk factors.

2976 These effects are tactical (i.e., local to a specific threat event or scenario), although it is possible
 2977 that their repeated achievement could have strategic effects as well. All effects except deter,
 2978 deceive, and exert apply to non-adversarial and adversarial threat events; deter, deceive, and
 2979 exert are applicable only to adversarial threat events.

2980 [Table F-1](#) defines the effects and provides informal notes in *italics*. It also indicates how each
 2981 effect could reduce risk and illustrates how the use of certain approaches to implementing cyber
 2982 resiliency techniques for protection against attack could have the identified effect. The term
 2983 *defender* refers to the organization or organizational personnel responsible for providing or
 2984 applying protections. It should be noted that likelihoods and impact can be reduced, but risk
 2985 cannot be eliminated. Thus, no effect can be assumed to be complete, even those with names
 2986 that suggest completeness, such as negate, detect, or expunge. [Table F-2](#) shows the potential
 2987 effects of cyber resiliency techniques on risk factors.

2988 TABLE F-1: EFFECTS OF CYBER RESILIENCY TECHNIQUES ON ADVERSARIAL THREAT EVENTS

| INTENDED EFFECT | IMPACT ON RISK | EXPECTED RESULTS |
|---|--|--|
| REDIRECT (includes deter, divert, and deceive) Direct the threat event away from defender-chosen resources. | Reduce the likelihood of occurrence, and (to a lesser extent) reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary's efforts cease. The adversary actions are mistargeted or misinformed. |
| DETER Discourage the adversary from taking an action by instilling fear (e.g., of attribution or retribution) or doubt that the action would achieve intended effects (e.g., that targets exist). <i>This effect is relevant only to adversarial threat events and involves influencing the adversary's decision-making process.</i> | Reduce the likelihood of occurrence. | <ul style="list-style-type: none"> The adversary ceases or suspends activities. <p>Example: The defender uses disinformation to make it appear that the organization is better able to detect attacks than it is and is willing to launch major counter-strikes. Therefore, the adversary chooses to not launch an attack due to fear of detection and reprisal.</p> |
| DIVERT Direct the threat event toward defender-chosen resources. <i>The event affects resources that the defender does not care about or for which the defender can manage consequences.</i> | Reduce the likelihood of occurrence. | <ul style="list-style-type: none"> The adversary refocuses activities on defender-chosen resources. The adversary directs activities toward targets beyond the defender's purview (e.g., other organizations). The adversary does not affect resources that the defender has not selected to be targets. <p>Example: The defender maintains an Internet-visible enclave with which untrusted external entities can interact and a private enclave accessible only via a VPN for trusted suppliers, partners, or customers (predefined segmentation). Example: The defender uses non-persistent information and obfuscation to hide critical resources combined with functional relocation of cyber resources and disinformation to lure the adversary toward a sandboxed</p> |

| INTENDED EFFECT | IMPACT ON RISK | EXPECTED RESULTS |
|--|---|--|
| | | enclave where adversary actions cannot harm critical resources. |
| DECEIVE Lead the adversary to believe false information about individuals, systems, missions, organizations, defender capabilities, or TTPs. <i>This effect is relevant only to adversarial threat events and involves influencing the adversary's actions.</i> | Reduce the likelihood of occurrence, and/or reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary's efforts are wasted as the assumptions on which the adversary bases attacks are false. The adversary takes actions based on false information, thus revealing that they have obtained that information. <p>Example: The defender strategically places false information (disinformation) about the cybersecurity investments that it plans to make. As a result, the adversary's malware development is wasted by being focused on countering non-existent cybersecurity protections.</p> <p>Example: The defender uses selectively planted false information (disinformation) and honeynets (misdirection) to cause an adversary to focus its malware on virtual sandboxes while simultaneously employing obfuscation to hide the actual resources.</p> |
| PRECLUDE (includes expunge, preempt, and negate) Ensure that the threat event does not have an impact. | Reduce the likelihood of occurrence, and/or reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary's efforts or resources cannot be applied or are wasted. |
| EXPUNGE Remove resources that are known to be or suspected of being unsafe, incorrect, or corrupted. | Reduce the likelihood of impact of subsequent events in the same threat scenario. | <ul style="list-style-type: none"> A malfunctioning, misbehaving, or suspect resource is restored to normal operation. The adversary loses a capability for some period, as adversary-directed threat mechanisms (e.g., malicious code) are removed. Adversary-controlled resources are so badly damaged that they cannot perform any function or be restored to a usable condition without being entirely rebuilt. <p>Example: The defender uses virtualization to refresh critical software (non-persistent services) from a known good copy at random intervals (temporal unpredictability). As a result, malware that was implanted in the software is deleted.</p> |
| PREEMPT Forestall or avoid conditions under which the threat event could occur. <i>The threat event cannot have any consequences because it cannot actually occur.</i> | Reduce the likelihood of occurrence. | <ul style="list-style-type: none"> The adversary's resources cannot be applied, or the adversary cannot perform activities (e.g., because resources adversary requires are destroyed or made inaccessible). <p>Example: An unneeded network connection is disabled (non-persistent connectivity) so that an attack via that interface cannot be made.</p> <p>Example: A resource is repositioned (asset mobility) so that it cannot be affected by a threat event in its new location.</p> |
| NEGATE Create conditions under which the threat event cannot be expected to result in an impact. | Reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary can launch an attack, but it will not even partially succeed. The adversary's efforts are wasted as the assumptions on which the adversary based its attack are no longer valid, and as a result, the intended effects cannot be achieved. |

| INTENDED EFFECT | IMPACT ON RISK | EXPECTED RESULTS |
|---|---|---|
| <i>The threat event may produce consequences, but those consequences cannot produce an impact.</i> | | <p>Example: Subtle variations in critical software are implemented (synthetic diversity) and prevent the adversary's malware from compromising the targeted software.</p> |
| IMPEDE (includes contain, degrade, delay, and exert) Make it more difficult for the threat event to cause adverse impacts or consequences. <i>For adversarial threats, this involves decreasing the adversary's return on investment (ROI) for the threat event.</i> | Reduce the likelihood of impact, and reduce the level of impact. | <ul style="list-style-type: none"> Adversary activities are restricted in scope, fail to achieve full effect, do not take place in accordance with the adversary timeline, or require greater resources than the adversary had planned. |
| CONTAIN Restrict the effects of the threat event to a limited set of resources. <i>The consequences of the threat event are less extensive than they might otherwise be.</i> | Reduce the level of impact. | <ul style="list-style-type: none"> The adversary can affect fewer resources than planned. The value of the activity to the adversary, in terms of achieving the adversary's goals, is reduced. <p>Example: The defender organization makes changes to a combination of internal firewalls and logically separated networks (dynamic segmentation) to isolate enclaves in response to the detection of malware, limiting the effects of the malware to initially infected enclaves.</p> |
| DEGRADE Decrease the expected consequences of the threat event. <i>Because the consequences of the threat event are less severe than they would be without the mitigation, they could fail to produce an impact, or their impact could be lessened.</i> | Reduce the likelihood of impact, and/or reduce the level of impact. | <ul style="list-style-type: none"> Not all of the resources targeted by the adversary are affected, or the targeted resources are affected to a lesser degree than the adversary sought. <p>Example: The defender uses multiple browsers and operating systems (architectural diversity) on both end-user systems and some critical servers. The result is that malware targeted at specific software can only compromise a subset of the targeted systems; a sufficient number continue to operate to complete the mission or business function.</p> |
| DELAY Increase the amount of time needed for the threat event to result in adverse impacts. <i>Because the consequences of the threat event occur later than they would without the mitigation, they could fail to produce an impact, or their impact could be lessened.</i> | Reduce the likelihood of impact, and/or reduce the level of impact. | <ul style="list-style-type: none"> The adversary achieves the intended effects but not within the intended period. <p>Example: The protection measures (e.g., access controls, encryption) allocated to resources increase in number and strength based on resource criticality (calibrated defense-in-depth). The frequency of authentication challenges varies randomly (temporal unpredictability) and more often for more critical resources. The result is that it takes the attacker more time to successfully compromise the targeted resources.</p> |
| EXERT Increase the level of effort or resources needed for an adversary to achieve a given result. <i>This effect is relevant only to adversarial threat events</i> | Reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary gives up planned or partially completed activities in response to finding that additional effort or resources are needed. The adversary achieves the intended effects in their desired time frame but only by applying more resources. Thus, the adversary's return on investment (ROI) is decreased. |

| INTENDED EFFECT | IMPACT ON RISK | EXPECTED RESULTS |
|--|---|--|
| <i>and involves increasing the adversary's costs.</i> | | <ul style="list-style-type: none"> The adversary reveals TTPs they had planned to reserve for future use. <p>Example: The defender enhances the defenses of moderate-criticality components with additional mitigations (calibrated defense-in-depth). To overcome these, the adversary must tailor and deploy TTPs that they were planning to reserve for use against higher value defender targets.</p> <p>Example: The defender adds a large amount of valid but useless information to a data store (obfuscation), requiring the adversary to exfiltrate and analyze more data before taking further actions.</p> |
| LIMIT (includes shorten and reduce) Restrict the impacts of a realized threat event by limiting the damage or effects it causes in terms of time, system resources, and/or mission or business impacts. | Reduce the level of impact, and reduce the likelihood of impact of subsequent events in the same threat scenario. | <ul style="list-style-type: none"> The adversary's effectiveness is restricted. |
| SHORTEN Limit the duration of adverse consequences of a threat event. <i>Because the consequences of the threat event do not persist as long as they would without the mitigation, they could fail to produce an impact, or their impact could be lessened.</i> | Reduce the level of impact. | <ul style="list-style-type: none"> The time period during which the adversary's activities affect defender resources is limited. <p>Example: The defender employs a diverse set of suppliers (supply chain diversity) for time-critical components. As a result, when an adversary's attack on one supplier causes it to shut down, the defender can increase its use of the other suppliers, thus shortening the time during which it is without the critical components.</p> |
| REDUCE Decrease the degree of damage from a threat event. The degree of damage can have two dimensions: breadth (i.e., number of affected resources) and depth (i.e., level of harm to a given resource). <i>A decrease in the degree of damage lessens the impact.</i> | Reduce the level of impact. | <ul style="list-style-type: none"> The level of damage to organizational missions or business operations from adversary activities is reduced due to partial restoration or reconstitution of all affected resources. <p>Example: Resources determined to be corrupted or suspect (integrity checks, behavior validation) are restored from older, uncorrupted resources (protected backup and restore) with reduced functionality.</p> <ul style="list-style-type: none"> The level of damage to organizational missions or business operations from adversary activities is reduced due to full restoration or reconstitution of some of the affected resources. <p>Example: The organization removes one of three compromised resources and provides a new resource (replacement, specialization) for the same or equivalent mission or business functionality.</p> |
| EXPOSE (includes detect, scrutinize, and reveal) Reduce risk due to ignorance of threat events | Reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary loses the advantage of stealth as defenders are better prepared by developing and sharing threat intelligence. |

| INTENDED EFFECT | IMPACT ON RISK | EXPECTED RESULTS |
|---|---|---|
| and possible replicated or similar threat events in the same or similar environments. | | |
| <p>DETECT Identify a threat event or its effects by discovering or discerning the fact that the event is occurring, has occurred, or (based on indicators, warnings, and precursor activities) is about to occur. <i>Detection informs corrective actions.</i></p> | Reduce the likelihood of impact, and reduce the level of impact (depending on responses). | <ul style="list-style-type: none"> The adversary's activities become susceptible to defensive responses. <p>Example: The defender continually moves its sensors (functional relocation of sensors), often at random times (temporal unpredictability), to common points of egress from the organization. They combine this with the use of beacon traps (tainting). The result is that the defender can quickly detect efforts by the adversary to exfiltrate sensitive information.</p> |
| <p>SCRUTINIZE Analyze threat events and artifacts associated with threat events to develop indicators, assess damage, and identify patterns of exploiting vulnerabilities, predisposing conditions, and weaknesses. <i>Scrutiny informs more effective detection and risk response.</i></p> | Reduce the likelihood of impact. | <ul style="list-style-type: none"> The adversary loses the advantages of uncertainty, confusion, and doubt. The defender has a better understanding the adversary, based on an analysis of the adversary's activities, including the artifacts (e.g., malicious code) and effects associated with those activities and the correlation of activity-specific observations with other activities (as feasible), and thus can recognize adversary TTPs. <p>Example: The defender deploys honeynets (misdirection), inviting attacks by the adversary and allowing the adversary to apply its TTPs in a safe environment. The defender then analyzes (malware and forensic analysis) the malware captured in the honeynet to determine the nature of the attacker's TTPs, allowing it to develop appropriate defenses.</p> |
| <p>REVEAL Share information about risk factors and the relative effectiveness of remediation approaches with partners, stakeholder community, or the general public. <i>Threat information sharing supports common, joint, or coordinated risk responses. Information about threat events can be shared broadly or with a limited set of threat intelligence information-sharing partners.</i></p> | Reduce the likelihood of impact, particularly in the future. | <ul style="list-style-type: none"> The adversary loses the advantage of surprise and plausible deniability. The adversary's ability to compromise one organization's systems to attack another organization is impaired as awareness of adversary characteristics and behavior across the stakeholder community (e.g., across all computer security incident response teams that support a given sector that might be expected to be attacked by the same actor or actors) is increased. <p>Example: The defender participates in threat information sharing and uses dynamically updated threat intelligence data feeds (dynamic threat modeling) to inform actions (adaptive management).</p> |

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TABLE F-2: EFFECTS OF CYBER RESILIENCY TECHNIQUES ON RISK FACTORS

| | REDUCE IMPACT | REDUCE LIKELIHOOD OF IMPACT | REDUCE LIKELIHOOD OF OCCURENCE |
|------------------------------------|------------------|--------------------------------|-----------------------------------|
| <u>ADAPTIVE RESPONSE</u> | X | X | |
| <u>ANALYTIC MONITORING</u> | | X | |
| <u>CONTEXTUAL AWARENESS</u> | X | X | |
| <u>COORDINATED PROTECTION</u> | X | X | |
| <u>DECEPTION</u> | | X | X |
| <u>DIVERSITY</u> | X | X | |
| <u>DYNAMIC POSITIONING</u> | X | X | X |
| <u>NON-PERSISTENCE</u> | X | X | X |
| <u>PRIVILEGE RESTRICTION</u> | X | X | |
| <u>REALIGNMENT</u> | X | X | X |
| <u>REDUNDANCY</u> | X | X | |
| <u>SEGMENTATION</u> | X | X | |
| <u>SUBSTANTIATED INTEGRITY</u> | X | X | |
| <u>UNPREDICTABILITY</u> | X | X | |

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2993 **F.2 ANALYSIS OF POTENTIAL EFFECTS OF CYBER RESILIENCY**

2994 The focus of cyber resiliency is on mitigating attacks on systems and organizations from the APT.
 2995 It is important to understand what effects these mitigations have on adversaries. Mapping the
 2996 current or potential effects of mitigations to a threat taxonomy provides a structured way to
 2997 facilitate this understanding. This appendix presents the results of such analysis using ATT&CK
 2998 for Enterprise [[MITRE18](#)].

2999 ATT&CK provides a knowledge base of adversary tactics, techniques, and associated information
 3000 based on curated data sets of real-world observations. ATT&CK reflects the phases of an
 3001 adversary's attack lifecycle and the platforms (e.g., Windows) adversaries are known to target,
 3002 providing a taxonomy of adversarial TTPs with a focus on those used by external adversaries
 3003 executing cyber attacks against networked systems. For purposes of this analysis, the following
 3004 components of ATT&CK are relevant:

- 3005 • Tactics, denoting short-term, tactical adversary goals during an attack
- 3006 • Techniques, describing the means by which adversaries achieve tactical goals, and given
 3007 identifiers of the form T####
- 3008 • Detection methods for each technique, captured as descriptive text in ATT&CK

- 3009 • Mitigations, describing technologies and practices which have been observed (in one or
3010 more of the curated data sets) to mitigate the techniques with which they are
3011 associated, and given identifiers of the form M####

3012 ATT&CK also defines sub-techniques, describing more specific means by which adversaries
3013 achieve tactical goals at a lower level than techniques (typically related to specific technologies
3014 or platforms), and associates mitigations and detection methods with sub-techniques. ATT&CK
3015 provides information about APT groups and about malware used by one or more APT actors.
3016 However, the analysis presented below does not consider sub-techniques, groups, malware, or
3017 other information included in ATT&CK.

3018 **F.2.1. Assumptions and Caveats**

3019 The analysis is restricted to mitigations that apply one or more cyber resiliency approaches and
3020 use one or more cyber resiliency controls,¹³⁰ as identified in [Table E-1](#) and in the ATT&CK
3021 knowledge base from curated datasets of real-world data and assigned identifiers of the form
3022 M10##. The analysis also uses candidate mitigations¹³¹ defined by engineering analysis but not
3023 part of the ATT&CK knowledge base. Candidate mitigations are discussed in [Section F.2.4](#),
3024 presented in Tables F-17 through F-19, and assigned identifiers of the form CM11##, CM13##,
3025 and CM20##. The analysis excludes from consideration those ATT&CK mitigations that do not
3026 apply a cyber resiliency approach but instead use conventional security methods to mitigate the
3027 ATT&CK technique. The analysis is restricted to ATT&CK techniques and does not include
3028 ATT&CK sub-techniques.

3029 The analysis considers only the direct effects that a particular control could have when
3030 implemented and used as described in the context of the mitigation or candidate mitigation.
3031 Indirect effects are not identified. Therefore, this analysis does not consider related controls
3032 (i.e., base controls for identified cyber resiliency control enhancements, controls identified as
3033 related for cyber resiliency controls). Similarly, this analysis does not map controls that influence
3034 the system architecture (e.g., control enhancements to SA-8, Security and Privacy Engineering
3035 Principles).

3036 Some cyber resiliency controls do not appear in Tables F-3 through F-16. There are two reasons
3037 for a control not being referenced in the ATT&CK mapping. First, a control could be intended to
3038 address threats not represented in ATT&CK for Enterprise (e.g., insider threats, threats against
3039 ICS, threats from maintenance staff, attacks on wireless communications). Second, a control
3040 could have no effect on any specific adversary TTP, either directly or by intensifying the
3041 effectiveness of an existing mitigation or candidate mitigation. This is particularly the case for
3042 design principles and requirements on system development. The effects of these controls are
3043 inherently indirect.

3044 Note that this analysis simply *identifies* the potential effects of the implementation approaches.
3045 It does not and cannot assess how strongly any identified effect will be experienced by an APT

¹³⁰ For brevity, the term *control* will be used to include control enhancements (e.g., AC-6(1)) as well as base controls (e.g., AC-6).

¹³¹ A candidate mitigation is a mitigation, defined in the context of ATT&CK, which has not been derived from a curated data set. It is designated as a “candidate” to differentiate it from the mitigations in the ATT&CK knowledge base.

3046 actor.¹³² A more detailed analysis would require knowledge of the type of system (including the
3047 system architecture and the types of technologies used) and the organization to which the
3048 requirements are to be applied. In addition, more detailed analysis could go beyond mapping to
3049 adversary objectives and map to adversary actions or individual adversary TTPs (e.g., as defined
3050 by the ATT&CK framework). Finally, some effects are beyond what can be designed and
3051 implemented in a technical system or the system’s supporting processes and practices. For
3052 example, the detection of adversary Resource Development actions requires cyber and other
3053 types of intelligence gathering and analyses, which are beyond the scope of cyber resiliency.
3054 Similarly, the Reveal effect involves the use of cyber threat intelligence by other organizations.

3055 F.2.2 Potential Uses of Analysis

3056 By seeing which effects a given approach could potentially have on a threat event, the systems
3057 engineer can determine which approaches (and corresponding controls) could maximize the
3058 system’s chances of mitigating the adversary’s actions. Thus, using the tables of this appendix
3059 may reveal to a systems engineer that the approaches (and correspondingly, the controls) that
3060 they are planning to invest in are largely focused on detecting an adversary, containing an
3061 adversary’s assault, shortening the duration of a successful adversary attack, and reducing the
3062 damage from such an attack. Correspondingly, such an assessment would reveal to the system
3063 engineer that the organization’s planned investments may be lacking in controls that have other
3064 effects, such as diverting or deceiving the adversary or preempting or negating the adversary’s
3065 attempted attack. Such information can help the engineer and other stakeholders reconsider
3066 their cyber security investments so that they might be more balanced.

3067 The tables also reveal which approaches (and correspondingly, which controls) have multiple
3068 potential effects on the adversary and which have only a few potential effects on the adversary.
3069 Such information might help inform investment decisions by guiding stakeholders to controls
3070 that have multiple effects, including those in which the organization has not previously invested.

3071 A control or a cyber resiliency approach per se will not have an effect on an adversary TTP—
3072 effects are achieved by threat-aware implementation and use of controls and approaches. The
3073 descriptions of the candidate mitigations in [Section F.2.4](#) and [[Bodeau21](#)] indicate how the
3074 implementation and use of controls could have the identified effects. The descriptions of
3075 candidate mitigations, which are at a higher level of abstraction than cyber resiliency controls
3076 and approaches, and often involve multiple controls and approaches, could also serve as the
3077 starting points for system requirements.

3078 Note that not all adversary tactics are affected by all approaches. Some tactics are affected only
3079 by one or two approaches. This is generally the case for adversary tactics in the early stages
3080 (e.g., Reconnaissance, Resource Development), which largely involve adversary actions done
3081 prior to accessing a defender’s system.

3082 F.2.3 Results of Analysis

3083 Tables F-3 through F-16 present the results of the analysis of potential effects of cyber resiliency
3084 on ATT&CK techniques. For each ATT&CK technique, the analysis includes relevant mitigations

¹³² Any true measure of effectiveness will need to be defined and evaluated in a situated manner (i.e., by identifying assumptions about the architectural, technical, operational, and threat environments, as discussed in [Section 3.2.1](#)).

3085 or candidate mitigations,¹³³ cyber resiliency implementation approaches, the potential effects
 3086 on the adversary when the approaches are applied, and the controls that can be employed to
 3087 achieve the intended effects.

3088 TABLE F-3: POTENTIAL EFFECTS OF CYBER RESILIENCY ON RECONNAISSANCE TECHNIQUES

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|--|-------------------------|----------------------------|
| Active Scanning (T1595) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Passive Decoys (CM1104) | Misdirection | Divert, Deceive | SC-26 |
| | | Architectural Diversity | Divert, Exert | SC-29 |
| | Conceal Resources from Discovery (CM1160) | Obfuscation, Functional Relocation of Cyber Resources | Degrade, Exert, Shorten | SC-7(16) |
| | | Obfuscation | Degrade, Exert | SC-28(1), SC-30, SC-30(5) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Gather Victim Host Information (T1592) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | Passive Decoys (CM1104) | Misdirection | Divert, Deceive | SC-26 |
| | | Architectural Diversity | Divert, Exert | SC-29 |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| Gather Victim Identity Information (T1589) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | Tainting | Detect | SI-20 | |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Exert | AT-2(1), AT-2(5) |
| | | Self-Challenge | Exert | AT-2(1), AT-3(3) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Gather Victim Network Information (T1590) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |

¹³³ The purpose of defining *candidate mitigations* is to ensure that the analysis uses a consistent method to identify which cyber resiliency approaches and controls could affect a given ATT&CK technique and to capture the reasoning about how cyber resiliency effects could be achieved. In contrast to the mitigations of ATT&CK, which are derived from operational experience and curated data sets, candidate mitigations are based on engineering analysis.

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|------------------------|------------------------------------|
| Gather Victim Org Information (T1591) | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Phishing for Information (T1598) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | User Training (M1017) | Dynamic Threat Awareness | Preempt, Exert, Detect | AT-2(5) |
| | Adversarial Simulation (CM1107) | Dynamic Threat Awareness, Self-Challenge | Preempt | AT-2(1), AT-3(3) |
| Search Closed Sources (T1597) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | Active Decoys (CM1123) | Misdirection, Forensic and Behavioral Analysis | Detect | SC-35 |
| | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Detect | AT-2(1), AT-2(3), AT-2(5), AT-3(3) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(13) |
| | Adversarial Simulation (CM1107) | Self-Challenge | Detect | CA-8, CA-8(2) |
| | Collaborate to Counter Adversaries (CM1161) | Disinformation, Tainting | Deceive, Detect | SC-30(4), SI-20 |
| | | Dynamic Threat Awareness | Detect | PM-16 |
| Search Open Technical | Restrict Supply Chain Exposures (CM1162) | Obfuscation, Supply Chain Diversity | Exert | SR-3(2) |
| | | Disinformation | Deceive | SR-7 |
| | | Self-Challenge | Detect | SR-6(1), SR-7 |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------|---------------------------|
| Databases (T1596) | Adversarial Simulation (CM1107) | Self-Challenge | Detect | CA-8, CA-8(2) |
| | Restrict Supply Chain Exposures (CM1162) | Obfuscation, Supply Chain Diversity | Exert | SR-3(2) |
| | | Disinformation | Deceive | SR-7 |
| | | Self-Challenge | Detect | SR-6(1), SR-7 |
| Search Open Websites or Domains (T1593) | Present Decoy Data (CM1113) | Disinformation, | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| Search Victim-Owned Websites (T1594) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |

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TABLE F-4: POTENTIAL EFFECTS OF CYBER RESILIENCY ON RESOURCE DEVELOPMENT TECHNIQUES

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|--|----------------------------|--|
| Acquire Infrastructure (T1583) | Present Deceptive Information (CM1101) | Disinformation | Preempt, Detect | SC-30(4) |
| | Adversarial Simulation (CM1107) | Self-Challenge | Detect | CA-8, CA-8(2) |
| | Collaborate to Counter Adversaries (CM1161) | Dynamic Threat Awareness | Detect | PM-16 |
| Compromise Accounts (T1586) | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Detect | AT-2(1), AT-2(3), AT-2(5), AT-3(3) |
| | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect | AU-13, AU-13(3), RA-5(4), RA-10 |
| Compromise Infrastructure (T1584) | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect, Scrutinize, Reveal | AU-13, AU-13(3), PM-16, RA-5(4), RA-10 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|--------------------|---------------------------------|
| Develop Capabilities (T1587) | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect | PM-16, RA-10 |
| Establish Accounts (T1585) | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Detect | AT-2(1), AT-2(5), AT-3(3) |
| | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect | AU-13, AU-13(3), RA-5(4), RA-10 |
| Obtain Capabilities (T1588) | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Detect | AT-2(1), AT-2(5), AT-3(3) |
| | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect | PM-16, RA-10 |
| Stage Capabilities (T1608) | Restrict Supply Chain Exposures (CM1162) | Integrity Checks, Provenance Tracking | Detect | SR-5, SR-11 |
| | | Monitoring and Damage Assessment | Detect | SR-6(1), SR-10 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SR-10 |
| | | Predefined Segmentation | Contain | CM-7(7) |
| | Monitor External Sources (CM2043) | Monitoring and Damage Assessment, Dynamic Threat Awareness | Detect | PM-16, RA-10 |
| Supply Chain Compromise (T1195) | Restrict Supply Chain Exposures (CM1162) | Integrity Checks, Provenance Tracking | Detect | SR-5, SR-11 |
| | | Monitoring and Damage Assessment | Detect | SR-6(1), SR-10 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SR-10 |
| | | Predefined Segmentation | Contain | CM-7(7) |

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TABLE F-5: POTENTIAL EFFECTS OF CYBER RESILIENCY ON INITIAL ACCESS

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|--|------------------------------|---|
| Drive-By Compromise (T1189) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Exert | AC-4(21), AC-6(4), SC-18(5), SC-39, CM-7(6) |
| | Exploit Protection (M1050) | Integrity Checks | Delay, Exert | AC-4(8) |
| | | Behavior Validation | Detect, Exert | IR-4(13) |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| Exploit Public-Facing Application (T1190) | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Exert | AC-4(21), AC-6(4), SC-18(5), SC-39, CM-7(6) |
| | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Exert | AC-6(2) |
| | Monitor Logs (CM2004) | Behavior Validation | Detect | AU-6 |
| | Present Deceptive Information (CM1101) | Disinformation | Delay, Deter, Deceive, Exert | SC-30(4) |
| External Remote Services (T1133) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Disable or Remove Feature or Program (M1042) | Restriction | Preempt, Negate | CM-7(2) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Delay, Exert | IA-2(13) |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Preempt, Shorten | SC-10, SI-14(3) |
| | Minimize Data Retention or (CM1124) | Non-Persistent Information | Degrade, Preempt | SC-23(3) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|--------------------------|---------------------------|
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(13) |
| | | Sensor Fusion and Analysis | Detect | SI-4(16) |
| Hardware Additions (T1200) | Limit Access to Resource over Network (M1035) | Trust-Based Privilege Management | Preempt | AC-6(3), AC-6(10) |
| | Limit Hardware Installation (M1034) | Restriction | Preempt, Negate | CM-8(3) |
| | Authenticate Devices (CM1125) | Obfuscation, Integrity Checks | Preempt, Negate | IA-3(1) |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment | Detect | CM-8(3) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Preempt | SC-30(4) |
| Phishing (T1566) | User Training (M1017) | Dynamic Threat Awareness | Negate, Exert | AT-2(1), AT-2(3), AT-2(5) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Preempt | SC-30(4) |
| | Detonation Chamber (CM1103) | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-44 |
| | | Misdirection | Divert, Negate | SC-44 |
| | | Predefined Segmentation | Contain, Delay, Exert | SC-44 |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35, SC-44 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35, SC-44 |
| Replication Through Removable Media (T1091) | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2) |
| | Virtual Sandbox (CM1109) | Non-Persistent Services | Preempt, Shorten | SC-7(20) |
| | | Dynamic Segmentation and Isolation | Delay, Contain | SC-7(20) |
| | Removable Device Usage Detection (CM2008) | Monitoring and Damage Assessment | Detect | CM-8(3) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|----------------------|--|
| Supply Chain Compromise (T1195) | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | | Integrity Checks, Provenance Tracking | Detect | CM-14, SR-4(3) |
| | Software Stress Testing (CM2010) | Self-Challenge | Detect | SR-6(1) |
| | Physical Inspection (CM2011) | Integrity Checks | Detect | SR-9, SR-10 |
| | Component Provenance Validation (CM1105) | Provenance Tracking | Detect, Delay, Exert | SR-4, SR-4(1), SR-4(2), SR-4(3), SR-4(4) |
| | Supply Chain Diversity (CM1106) | Supply Chain Diversity | Exert | PL-8(2), SR-3(1), SR-3(2) |
| Trusted Relationship (T1199) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | SC-7, SC-7(21) |
| | Monitor Trusted Parties (CM2012) | Dynamic Threat Awareness | Detect | PM-16 |
| | | Behavior Validation | Detect | SI-10(3) |
| | | Provenance Tracking | Detect | PM-30(1) |
| Valid Accounts (T1078) | Privileged Account Management (M1026) | Trust-Based Privilege Management, Consistency Analysis | Preempt | AC-6(7) |
| | Present Deceptive Information (CM1101) | Disinformation | Exert | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3), SI-4(16) |

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TABLE F-6: POTENTIAL EFFECTS OF CYBER RESILIENCY ON EXECUTION

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|--|-------------------------------|-----------------------------|
| Command and Scripting Interpreter (T1059) | Code Signing (M1045) | Provenance Tracking | Preempt | SI-7(15) |
| | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2), SC-3(3) |
| | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-7(4), CM-7(5) |
| | Monitor Script Execution (CM2029) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(13) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(13) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--|---------------------------|
| Active Deception (T1131) | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Quarantine or Delete Suspicious Files (CM1132) | Provenance Tracking | Detect | SR-4(3) |
| | | Dynamic Segmentation and Isolation | Contain, Delay, Degrade, Exert | CM-7(6) |
| | | Non-Persistent Information | Expunge | SI-14, SI-14(2) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26, SI-3(10) |
| Container Administration Command (T1609) | Execution Prevention (M1038) | Non-Persistent Services, Provenance Tracking | Negate, Exert | SI-14(1) |
| | Execution Prevention (CM1111) | Attribute-Based Usage Restriction | Degrade, Exert | AC-3(13) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12), SI-4(16) |
| Deploy Container (T1610) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | SC-7 |
| | User Account Management (M1018) | Trust-Based Privilege Management | Degrade, Exert | AC-6(7) |
| | Calibrate Administrative Access (CM1164) | Attribute-Based Usage Restriction | Degrade, Exert | AC-6 |
| | | Trust-Based Privilege Management | Degrade, Exert | AC-6(5) |
| | | Restriction | Degrade, Exert | CM-7(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|--|--------------------------------------|
| | Analyze Logs (CM2005) | Sensor Fusion and Analysis | Detect | SI-4(16) |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Exploitation for Client Execution (T1203) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Negate, Delay, Degrade, Exert | AC-4(21), AC-6(4), SC-39, CM-7(6) |
| | Detonation Chamber (CM1103) | Predefined Segmentation | Negate | SC-44 |
| | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | Endpoint Scrutiny (CM2019) | Forensic and Behavioral Analysis | Scrutinize, Detect | IR-4(12) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Inter-Process Communication (T1559) | Behavior Prevention on Endpoint (M1040) | Restriction | Exert, Preempt | CM-7(2) |
| | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2) |
| | Network Segmentation (M1030) | Predefined Segmentation | Negate | SC-7 |
| | Monitor Use of Libraries and Utilities (CM2040) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4), SI-4(13) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|-----------------------------------|---|---|--|---------------------------|
| | | Monitoring and Damage Assessment | Detect | SI-4(11), SI-4(13) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Native API (T1106) | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-7(5) |
| | Host-Local Event Correlation (CM2022) | Sensor Fusion and Analysis | Detect | IR-4(13), SI-4(16) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| Scheduled Task/Job (T1053) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect, Scrutinize | SC-26 |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|--|---------------------------|
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |
| Shared Modules (T1129) | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-7(5) |
| | Execution Restriction (CM1111) | Attribute-Based Usage Restriction | Negate, Delay, Degrade, Exert | AC-3(13) |
| | Host-Local Event Correlation (CM2022) | Sensor Fusion and Analysis | Detect | IR-4(13), SI-4(16) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Software Deployment Tools (T1072) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Exert | AC-6(5) |
| | Remote Data Storage (M1029) | Predefined Segmentation, Trust-Based Privilege Management | Exert | AC-6(4) |
| | User Account Management (M1018) | Trust-Based Privilege Management | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | | Consistency Analysis | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | Isolate or Contain Selected Applications or Components (CM1133) | Trust-Based Privilege Management | Degrade, Exert, Shorten, Reduce | CM-7(6) |
| | | Predefined Segmentation | Contain | CM-7(6) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--------------------------------|---|--|--|---------------------------|
| System Services (T1569) | Monitor Trusted Parties (CM2012) | Dynamic Threat Awareness | Detect | PM-16 |
| | | Provenance Tracking | Detect | PM-30(1) |
| | | Dynamic Resource Awareness | Detect | SI-4(17) |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5), AU-6(3) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| | | | | |
| | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Exert | AC-6(8) |
| | User Account Management (M1018) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(13) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | AU-6 |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--|----------------------------|
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| User Execution (T1204) | Restrict Web-Based Content (M1021) | Integrity Checks | Preempt, Exert | AC-4(8) |
| | Minimize Local Functionality (CM1119) | Restriction | Contain, Preempt | CM-7(2), SC-25 |
| | Identify External Malware (CM1136) | Monitoring and Damage Assessment | Detect | SC-35 |
| | | Forensic and Behavioral Analysis | Scrutinize | SC-35 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Windows Management Instrumentation (T1047) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Degrade, Delay, Exert | AC-6(5) |
| | | Trust-Based Privilege Management | Negate, Degrade, Delay, Exert | AC-6(7) |
| | | Consistency Analysis | Degrade, Delay, Exert | AC-6(7) |
| | Calibrate Administrative Access (CM1164) | Attribute-Based Usage Restriction | Exert | AC-6 |
| | | Trust-Based Usage Restriction | Exert | AC-6(5) |
| | | Restriction | Exert | CM-7(2) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|------------------------------------|--|--|---------------------------|
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |

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TABLE F-7: POTENTIAL EFFECTS OF CYBER RESILIENCY ON PERSISTENCE

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|-------------------------------------|---|--|--------------------------------|---------------------------|
| Account Manipulation (T1098) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Delay, Preempt | AC-4(21), SC-7(20) |
| | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(2) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Degrade, Exert | IA-2(13) |
| BITS Jobs (T1197) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | AC-2(12) |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|--|--------------------------|-----------------------------|
| | | Disinformation | Deceive | SC-30(4) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Boot or Logon Autostart Execution (T1547) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Information | Expunge, Negate | SI-14(2) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Boot or Logon Initialization Scripts (T1037) | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Negate | SI-14(1) |
| | Monitor Script Execution (CM2029) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(13) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|--------------------------|---------------------------|
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Browser Extensions (T1176) | Audit (M1047) | Provenance Tracking | Detect, Negate | AU-10(2) |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13) |
| Compromise Client Software Binary (T1554) | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Code Signing (M1045) | Provenance Tracking | Detect | SI-7(15) |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Endpoint Scrutiny (CM2019) | Forensic and Behavioral Analysis | Detect, Scrutinize | IR-4(12) |
| Create Account (T1136) | Software Integrity Check (CM2009) | Integrity Checks | Detect, Scrutinize | SI-7(1), SI-7(6) |
| | Check Policy Consistency (CM1129) | Consistency Analysis | Degrade, Exert, Detect | CA-7(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Create or Modify System Process (T1543) | Audit (M1047) | Consistency Analysis | Detect | CA-7(5) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7, SI-7(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|-------------------------------|---------------------------|
| Event Triggered Execution (T1546) | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7, SI-7(1) |
| External Remote Services (T1133) | Disable or Remove Feature or Program (M1042) | Restriction | Preempt, Negate | CM-7(2) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Delay, Exert | IA-2(13) |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Expunge, Shorten | SC-10, SI-14(3) |
| | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Exert, Preempt | SC-23(3) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | AU-6 |
| Hijack Execution Flow (T1574) | Audit (M1047) | Non-Persistent Information | Preempt, Exert | SI-14(2) |
| | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-7(5) |
| | Restrict File and Directory Permissions (M1022) | Integrity Checks | Preempt, Exert | SC-34 |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| | Validate Data Properties (CM1137) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | | Calibrated Defense-in-Depth | Delay, Degrade | PL-8(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|-----------------------------|------------------------------|
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |
| Implant Container Image (T1525) | Audit (M1047) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | Code Signing (M1045) | Provenance Tracking | Preempt | SI-7(15) |
| | Account Monitoring (CM2021) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Office Application Startup (T1137) | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Pre-OS Boot (T1542) | Boot Integrity (M1046) | Integrity Checks | Detect | SI-6, SI-7, SI-7(1), SI-7(9) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Information | Expunge, Shorten | SI-14(1) |
| | Endpoint Scrutiny (CM2019) | Forensic and Behavioral Analysis | Detect | IR-4(12) |
| | Hardware-Based Protection of Firmware (CM1154) | Integrity Checks | Negate, Preempt | SC-51 |
| | Host-Local Event Correlation (CM2022) | Sensor Fusion and Analysis | Detect | IR-4(13), SI-4(16) |
| Scheduled Task/Job (T1053) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect, Scrutinize | SC-26 |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|--|---------------------------------|----------------------------|
| Server Software Component (T1505) | Audit (M1047) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | Code Signing (M1045) | Provenance Tracking | Preempt | SI-7(15) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | | Sensor Fusion and Analysis | Detect | SI-4(16) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Traffic Signaling (T1205) | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Preempt, Exert | SC-10, SI-14(3) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Valid Accounts (T1078) | Privileged Account Management (M1026) | Trust-Based Privilege Management, Consistency Analysis | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | | Consistency Analysis | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3), SI-4(16) |

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TABLE F-8: POTENTIAL EFFECTS OF CYBER RESILIENCY ON PRIVILEGE ESCALATION

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|------------------------|--------------------------------|
| Abuse Elevation Control Mechanism (T1548) | Execution Prevention (M1038) | Purposing | Negate | CM-7(5) |
| | Partition Host (CM1118) | Predefined Segmentation | Delay, Negate, Contain | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|--------------------------|--------------------------------|
| Access Token Manipulation (T1134) | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-26, SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Partition Host (CM1118) | Predefined Segmentation | Delay, Negate, Contain | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Enhanced Authentication (CM1126) | Adaptive Management, Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-10 |
| | | Architectural Diversity, Design Diversity, Adaptive Management | Delay, Exert | CP-13 |
| | | Path Diversity | Delay, Exert | SC-47 |
| | Validate Data Properties (CM1137) | Integrity Checks | Negate, Detect | SC-16(1), SC-16(3) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Process Analysis (CM2014) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Boot or Logon Autostart Execution (T1547) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Information | Expunge, Negate | SI-14(2) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------------|-----------------------------|
| Boot or Logon Initialization Scripts (T1037) | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Negate | SI-14(1) |
| | Monitor Script Execution (CM2029) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(13) |
| Create or Modify System Process (T1543) | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Audit (M1047) | Consistency Analysis | Detect | CA-7(5) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| Escape to Host (T1611) | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | Application Isolation and Sandboxing (M1048) | Restriction | Contain, Exert | CM-7(2) |
| | Execution Prevention (M1038) | Non-Persistent Services | Negate, Exert | SC-34, SC-34(1) |
| | Privileged Account Management (M1026) | Attribute-Based Usage Restriction | Exert | AC-6 |
| | Analyze Logs (CM2005) | Sensor Fusion and Analysis | Detect | SI-4(16) |
| Event Triggered Execution (T1546) | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|--|---|
| | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7, SI-7(1) |
| Exploitation for Privilege Escalation (T1068) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Exert | AC-4(21), AC-6(4), SC-18(5), SC-39, CM-7(6) |
| | Exploit Protection (M1050) | Integrity Checks | Delay, Exert | AC-4(8) |
| | | Behavior Validation | Detect, Exert | IR-4(13) |
| | Threat Intelligence Program (M1019) | Dynamic Threat Awareness | Exert, Preempt | PM-16, RA-3(3) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Exert, Scrutinize, Reveal ¹³⁴ | SI-20 |
| Group Policy Modification (T1484) | Refresh Selected Applications or Components (CM1134) | Non-Persistent Information | Expunge, Shorten | SI-14(1) |
| | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| | User Account Management (M1018) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(13) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| Hijack Execution Flow (T1574) | Lock Down Visibility or Access (CM1149) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(11) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | Audit (M1047) | Non-Persistent Information | Preempt, Exert | SI-14(2) |
| | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-4(4), CM-7(5) |
| | Restrict File and Directory Permissions (M1022) | Integrity Checks | Preempt, Exert | SC-34 |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |

¹³⁴ The Reveal effect is identified only for some uses of [CM1101](#). Reveal can be an effect if the organization uses the PM-16 control—which is cited by M1019, [CM2012](#), and [CM1301](#)—to share threat information that it develops with other organizations rather than simply being a consumer of threat information developed by other organizations.

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|-----------------------------------|--|---|---------------------------------|---------------------------|
| Process Injection (T1055) | Validate Data Properties (CM1137) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | | Calibrated Defense-in-Depth | Delay, Degrade | PL-8(1) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |
| | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Degrade | AC-6(7) |
| | | Attribute-Based Usage Restriction | Negate, Degrade | AC-6(8) |
| | | Functional Relocation of Cyber Resources | Shorten | SC-30(3) |
| | | | Shorten | SI-14(1) |
| | | Non-Persistent Services | | |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Process Analysis (CM2014) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Scheduled Task/Job (T1053) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect, Scrutinize | SC-26 |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |
| Valid Accounts (T1078) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3) SI-4(16) |

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TABLE F-9: POTENTIAL EFFECTS OF CYBER RESILIENCY ON DEFENSE EVASION

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|------------------------|--------------------------------|
| Abuse Elevation Control Mechanism (T1548) | Execution Prevention (M1038) | Purposing | Negate | CM-7(5) |
| | Partition Host (CM1118) | Predefined Segmentation | Delay, Negate, Contain | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Access Token Manipulation (T1134) | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-26, SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Partition Host (CM1118) | Predefined Segmentation | Delay, Negate, Contain | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Validate Data Properties (CM1137) | Integrity Checks | Negate, Detect | SC-16(1), SC-16(3) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Process Analysis (CM2014) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| BITS Jobs (T1197) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Build Image on Host (T1612) | Audit (M1047) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | Network Segmentation (M1030) | Predefined Segmentation | Negate, Degrade, Exert | SC-7 |
| | Execution Prevention (CM1111) | Attribute-Based Usage Restriction | Degrade, Exert | AC-3(12) |
| | Lock Down Visibility or Access (CM1149) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(11) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|--|-----------------------------|
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Deobfuscate/Decode Files or Information (T1140) | Application- or Utility-Specific Data Removal (CM1110) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Integrity Checks | Detect | SI-7(1), SI-7(7) |
| | | Dynamic Reconfiguration | Expunge | IR-4(2) |
| | Host-Local Event Correlation (CM2022) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(16) |
| Deploy Container (T1610) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | SC-7 |
| | User Account Management (M1018) | Trust-Based Privilege Management | Degrade, Exert | AC-6(7) |
| | Calibrate Administrative Access (CM1164) | Attribute-Based Usage Restriction | Degrade, Exert | AC-6 |
| | | Trust-Based Privilege Management | Degrade, Exert | AC-6(5) |
| | | Restriction | Degrade, Exert | CM-7(2) |
| | Analyze Logs (CM2005) | Sensor Fusion and Analysis | Detect | SI-4(16) |
| Direct Volume Access (T1006) | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Present Decoy Data (CM1113) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Execution Guardrails (T1480) | Active Deception (CM1131) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(13) |
| | | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 | |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|--|-----------------------------------|
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Exploitation for Defense Evasion (T1211) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Exert | AC-4(21), AC-6(4), SC-39, CM-7(6) |
| | Exploit Protection (M1050) | Integrity Checks | Delay, Exert | AC-4(8) |
| | Threat Intelligence Program (M1019) | Dynamic Threat Awareness | Exert, Preempt | PM-16, RA-3(3) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| File and Directory Permissions Modification (T1222) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(7) |
| | | Attribute-Based Usage Restriction | Negate, Delay, Degrade, Exert | AC-6(8) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Exert, Scrutinize, Reveal | SI-20 |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | | Sensor Fusion and Analysis | Detect | SI-4(16) |
| Group Policy Modification (T1484) | User Account Management (M1018) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(13) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--------------------------------------|---|--|-------------------------------|---------------------------|
| | Lock Down Visibility or Access (CM1149) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(11) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| Hide Artifacts (T1564) | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |
| Hijack Execution Flow (T1574) | Audit (M1047) | Non-Persistent Information | Preempt, Exert | SI-14(2) |
| | Execution Prevention (M1038) | Purposing | Negate, Delay, Degrade, Exert | CM-7(5) |
| | Restrict File and Directory Permissions (M1022) | Integrity Checks | Preempt, Exert | SC-34 |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| | Validate Data Properties (CM1137) | Integrity Checks | Detect | SI-7, SI-7(1) |
| | | Calibrated Defense-in-Depth | Delay, Degrade | PL-8(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|---|--|------------------------|----------------------------|
| Impair Defenses (T1562) | Restrict File and Directory Permissions (M1022) | Attribute-Based Usage Restriction | Negate, Degrade, Exert | AC-6(1) |
| | User Account Management (M1018) | Attribute-Based Usage Restriction | Negate, Degrade, Exert | AC-6(1) |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Indicator Removal on Host (T1070) | Encrypt Sensitive Information (M1041) | Obfuscation | Degrade, Exert | AU-9(3), SC-8(4), SC-28(1) |
| | Remote Data Storage (M1029) | Predefined Segmentation | Degrade, Exert | AU-9(2) |
| | | Non-Persistent Information | Degrade, Exert | SI-14(2) |
| | | Integrity Checks | Degrade, Exert | AU-9(6) |
| | Restrict File and Directory Permissions (M1022) | Trust-Based Privilege Management | Degrade, Exert | AU-9(6) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Defend Audit Data (CM1158) | Integrity Checks | Negate | AU-9(1) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Indirect Command Execution (T1202) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | | Sensor Fusion and Analysis | Detect | SI-4(16) |
| Masquerading (T1036) | Code Signing (M1045) | Provenance Tracking | Detect | SI-7(15) |
| | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------------|---------------------------------|
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |
| Modify Authentication Process (T1556) | Privileged Account Management (M1026) | Consistency Analysis, Trust-Based Privilege Management | Degrade, Exert, Shorten | AC-6(7) |
| | Enhanced Authentication (CM1126) | Adaptive Management, Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-10 |
| | | Architectural Diversity, Design Diversity, Adaptive Management | Delay, Exert | CP-13 |
| | | Path Diversity | Delay, Exert | SC-47 |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5) |
| | Account Monitoring (CM2021) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| Modify Cloud Compute Infrastructure (T1578) | Centralize and Analyze Instance Logging (CM2023) | Sensor Fusion and Analysis | Detect | AU-6(5), IR-4(4) |
| Modify Registry (T1112) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Modify System Image (T1601) | Boot Integrity (M1046) | Integrity Checks | Detect | SI-7, SI-7(1), SI-7(6), SI-7(9) |
| | Code Signing (M1045) | Provenance Tracking | Preempt | SI-7(15), SR-4(3) |
| | Credential Access Protection (M1043) | Standard practice | Delay, Exert | IA-5(7), SC-28(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------------------|----------------------------|
| Network Boundary Bridging (T1599) | Privileged Account Management (M1026) | Consistency Analysis, Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(5) |
| | Validate Data Properties (CM1137) | Integrity Checks | Negate, Detect | SC-16(1), SC-16(3) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services, Non-Persistent Information, Provenance Tracking | Expunge, Exert, Shorten | SI-14(1) |
| | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7(6) |
| Obfuscated Files or Information (T1027) | Filter Network Traffic (M1037) | Adaptive Management | Degrade, Reduce | AC-4(3) |
| | | Dynamic Reconfiguration | Degrade, Reduce | IR-4(2) |
| | | Monitoring and Damage Assessment | Detect | SI-4(4) |
| | Privileged Account Management (M1026) | Consistency Analysis, Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(5) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services, Non-Persistent Information | Expunge, Exert, Shorten | SI-14(1) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| | Enhance via Heterogeneity (CM1305) | Architectural Diversity | Exert | AU-9(7), SC-29, SC-29(1) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Pre-OS Boot (T1542) | Detonation Chamber (CM1103) | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-44 |
| | Application- or Utility-Specific Data Removal (CM1110) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Integrity Checks | Detect | SI-7(1), SI-7(7) |
| | | Dynamic Reconfiguration | Expunge | IR-4(2) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------|---------------------------|
| | Hardware-Based Protection of Firmware (CM1154) | Integrity Checks | Negate, Preempt | SC-51 |
| | Endpoint Scrutiny (CM2019) | Forensic and Behavioral Analysis | Detect | IR-4(12) |
| Process Injection (T1055) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Degrade | AC-6(7) |
| | | Attribute-Based Usage Restriction | Negate, Degrade | AC-6(8) |
| | Dynamically Relocate and Refresh Processing (CM1150) | Functional Relocation of Cyber Resources | Shorten | SC-30(3) |
| | | Non-Persistent Services | Shorten | SI-14(1) |
| | Defend Against Memory Attacks (CM1152) | Synthetic Diversity, Temporal Unpredictability | Negate, Exert | SI-16 |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Rogue Domain Controller (T1207) | Validate Data Quality (CM1130) | Integrity Checks | Detect, Shorten | SI-7(1) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Rootkit (T1014) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Calibrate Administrative Access (CM1164) | Attribute-Based Usage Restriction | Exert | AC-6 |
| | | Trust-Based Usage Restriction | Exert | AC-6(5) |
| | | Restriction | Exert | CM-7(2) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|--|---------------------------|
| Signed Binary Proxy Execution (T1218) | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(7) |
| | | Attribute-Based Usage Restriction | Negate, Delay, Degrade, Exert | AC-6(8) |
| | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2), SC-3(3) |
| | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Quarantine or Delete Suspicious Files (CM1132) | Provenance Tracking | Detect | SR-4(3) |
| | | Dynamic Segmentation and Isolation | Contain, Delay, Degrade, Exert | CM-7(6) |
| | | Non-Persistent Information | Expunge | SI-14, SI-14(2) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Signed Script Proxy Execution (T1216) | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Quarantine or Delete Suspicious Files (CM1132) | Provenance Tracking | Detect | SR-4(3) |
| | | Dynamic Segmentation and Isolation | Contain, Delay, Degrade, Exert | CM-7(6) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|--|--|--|------------------------------|
| Subvert Trust Controls (T1553) | | Non-Persistent Information | Expunge | SI-14, SI-14(2) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | SI-4(2) |
| | Monitor Script Execution (CM2029) | Monitoring and Damage Assessment | Detect | IR-4(13) , SI-4(2), SI-4(13) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | Forensic and Behavioral Analysis | Detect, Scrutinize | | SC-26 |
| | Execution Prevention (M1038) | Purposing | Negate, Exert | CM-7(5) |
| | Software Configuration (M1054) | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Expunge, Shorten | SC-23(3), SI-14(2), SI-21 |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|--|----------------------------|
| Template Injection (T1221) | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(13) |
| | Software Integrity Check (CM2009) | Integrity Checks | Detect | SI-7(6) |
| Traffic Signaling (T1205) | Antivirus/Antimalware (M1049) | Predefined Segmentation | Negate, Contain | SC-44 |
| | Disable or Remove Feature or Program (M1042) | Restriction | Negate, Degrade | CM-7(2) |
| | Network Intrusion Prevention (M1031) | Predefined Segmentation | Negate, Contain | SC-44 |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Trusted Developer Utilities Proxy Execution (T1127) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Preempt, Exert | SC-10, SI-14(3) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Unused/ Unsupported Cloud Regions (T1535) | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2), SC-3(3) |
| | Execution Prevention (M1038) | Purposing | Exert, Preempt | CM-7(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Use Alternate Authentication | Software Configuration (M1054) | Attribute-Based Usage Restriction | Negate | AC-3(13) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | AU-6, SI-4(11) |
| Use Alternate Authentication | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Exert | SC-23(3), SI-14(2), SI-21 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|--|--------------------------------|---------------------------|
| Material (T1550) | | Temporal Unpredictability | Exert | SC-23(3) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-10 |
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3), SI-4(16) |
| Valid Accounts (T1078) | Privileged Account Management (M1026) | Consistency Analysis, Trust-Based Privilege Management | Preempt | AC-6(7) |
| | Present Deceptive Information (CM1101) | Disinformation | Exert | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3), SI-4(16) |
| Virtualization/Sandbox Evasion (T1497) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Active Decoys (CM1123) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | | Misdirection | Detect, Scrutinize | SC-35 |
| | | Dynamic Segmentation and Isolation | Contain | SC-35 |
| Weaken Encryption (T1600) | Execution Restriction (CM1111) | Attribute-Based Usage Restriction | Negate, Degrade, Exert | AC-3(13) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services, Non-Persistent Information, Provenance Tracking | Expunge, Exert, Shorten | SI-14(1) |
| XSL Script Processing (T1220) | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Quarantine or Delete Suspicious Files (CM1132) | Provenance Tracking | Detect | SR-4(3) |
| | | Dynamic Segmentation and Isolation | Contain, Delay, Degrade, Exert | CM-7(6) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|---|--|-------------------|---------------------------|
| | | Non-Persistent Information | Expunge | SI-14(2) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

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TABLE F-10: POTENTIAL EFFECTS OF CYBER RESILIENCY ON CREDENTIAL ACCESS

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|------------------------------|-----------------------------------|
| Brute Force (T1110) | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Degrade, Exert | IA-2(13) |
| | Design Diversity (CM1128) | Design Diversity | Delay, Exert | SA-17(9) |
| | Present Deceptive Information (CM1101) | Disinformation | Delay, Deter, Deceive, Exert | SC-30(4) |
| | Tainting | | Detect, Scrutinize | SI-20 |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| Credentials from Password Stores (T1555) | Check Policy Consistency (CM1129) | Consistency Analysis | Degrade, Exert | CA-7(5) |
| | Present Deceptive Information (CM1101) | Disinformation | Delay, Deter, Deceive, Exert | SC-30(4) |
| | Monitor the File System (CM2033) | Tainting | Detect, Scrutinize | SI-20 |
| Exploitation for Credential Access (T1212) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Delay, Preempt | AC-4(21), AC-6(4), SC-39, CM-7(6) |
| | Exploit Protection (M1050) | Integrity Checks | Delay, Exert | AC-4(8) |
| | Threat Intelligence Program (M1019) | Dynamic Threat Awareness | Exert, Preempt | PM-16, RA-3(3) |
| | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | AC-2(12) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--------------------------------------|--|---|--|---------------------------|
| Forced Authentication (T1187) | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| Input Capture (T1056) | Trusted Path (CM1120) | Predefined Segmentation | Negate, Contain | SC-11 |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12), SI-4(16) |
| | | Dynamic Resource Awareness | Detect | SI-4(16) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Man-in-the-Middle (T1557) | Disable or Remove Feature or Program (M1042) | Restriction | Negate, Exert | CM-7(2), SC-3(3) |
| | Filter Network Traffic (M1037) | Provenance Tracking | Negate, Exert | SC-7(11), SI-10(5) |
| | Limit Access to Resource Over Network (M1035) | Trust-Based Privilege Management | Negate, Exert | AC-6(3) |
| | Network Intrusion Prevention (M1031) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(4) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Degrade, Exert | SC-7 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|--|--------------------------------|---------------------------|
| Modify Authentication Process (T1556) | Privileged Account Management (M1026) | Consistency Analysis, Trust-Based Privilege Management | Negate, Delay, Degrade, Exert | AC-6(7) |
| | Enhanced Authentication (CM1126) | Adaptive Management, Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-10 |
| | | Architectural Diversity, Design Diversity, Adaptive Management | Delay, Exert | CP-13 |
| | | Path Diversity | Delay, Exert | SC-47 |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5) |
| | Account Monitoring (CM2021) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| Network Sniffing (T1040) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Exert | SC-8(4) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Degrade, Exert | IA-2(13) |
| | Privileged Account Monitoring (CM2017) | Monitoring and Damage Assessment | Detect | AC-6(8) ¹³⁵ |
| OS Credential Dumping (T1003) | Credential Access Protection (M1043) | Standard practice | Preempt, Exert | IA-5, SC-29(1) |
| | Operating System Configuration (M1028) | Restriction | Preempt | CM-7(2) |
| | Privileged Process Integrity (M1025) | Restriction | Preempt | CM-7(2) |
| | Hide Sensitive Information (CM1135) | Obfuscation | Delay, Exert | SC-28(1) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |

¹³⁵ AC-6(8) also applies Predefined Segmentation. However, that aspect of the control is intended to address Defense Evasion.

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------------------|------------------------------------|
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13) |
| | Adversarial Simulation (CM1107) | Self-Challenge | Preempt | CA-8, CA-8(2) |
| Steal Application Access Token (T1528) | Audit (M1047) | Standard practice | | |
| | Restrict Web-Based Content (M1021) | Trust-Based Privilege Management | Negate, Exert | AC-6(4) |
| | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | Detect | AT-2(1), AT-2(3), AT-2(5), AT-3(3) |
| | Hunt for Malicious Processes (CM2048) | Forensic and Behavioral Analysis | Detect | IR-5 |
| Steal or Forge Kerberos Tickets (T1558) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Exert | SC-30 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Exert | SC-30(4) |
| Steal Web Session Cookie (T1539) | Software Configuration (M1054) | Non-Persistent Information | Degrade, Exert | SI-14(2), SI-21 |
| | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Expunge, Shorten | SI-14(2) |
| Two-Factor Authentication Interception (T1111) | Monitor Logs (CM2004) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6 |
| Unsecured Credentials (T1552) | Encrypt Sensitive Information (M1041) | Calibrated Defense-in-Depth, Obfuscation | Negate, Degrade, Exert | SC-28(1), IA-2(6) |
| | Filter Network Traffic (M1037) | Restriction | Negate, Degrade, Exert | SC-3(3) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Partition Host (CM1118) | Predefined Segmentation | Contain, Delay, Exert | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(3), AU-6(5) |

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TABLE F-11: POTENTIAL EFFECTS OF CYBER RESILIENCY ON DISCOVERY

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|---------------------------------|---------------------------|
| Account Discovery (T1087) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Exert, Reveal, Scrutinize | SI-20 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Application Window Discovery (T1010) | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Browser Bookmark Discovery (T1217) | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Cloud Infrastructure Discovery (T1580) | User Account Management (M1018) | Trust-Based Privilege Management | Degrade | AC-6 |
| | | Consistency Analysis | Exert | AC-6(7) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | AU-6 |
| Cloud Service Dashboard (T1538) | User Account Management (M1018) | Trust-Based Privilege Management | Degrade | AC-6 |
| | | Consistency Analysis | Exert | AC-6(7) |
| | Monitor Logs (CM2004) | Monitoring and Damage Assessment | Detect | AU-6 |
| Cloud Service Discovery (T1526) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | Passive Decoys (CM1104) | Misdirection | Divert, Deceive, Degrade, Exert | SC-26 |
| | | Architectural Diversity | Divert, Deceive, Degrade, Exert | SC-29 |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|------------------------------|---------------------------|
| Container and Resource Discovery (T1613) | Network Segmentation (M1030) | Predefined Segmentation | Negate, Degrade, Exert | SC-7, SC-7(21) |
| | User Account Management (M1018) | Attribute-Based Usage Restriction | Degrade | AC-6 |
| | | Consistency Analysis | Exert | AC-6(7) |
| | Defend Audit Data (CM1158) | Predefined Segmentation | Negate, Exert | AU-9(2) |
| | Centralize and Analyze Instance Logging (CM2023) | Sensor Fusion and Analysis | Detect | AU-6(5), IR-4(4) |
| Domain Trust Discovery (T1482) | Audit (M1047) | Consistency Analysis | Exert | CA-7(5) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | AC-4(2), AC-4(21), SC-7 |
| | Present Deceptive Information (CM1101) | Disinformation | Delay, Deter, Deceive, Exert | SC-30(4) |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| File and Directory Discovery (T1083) | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Divert, Delay | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources | Preempt | SC-30(3) |
| | | Temporal Unpredictability | Preempt, Exert | SC-30(3) |
| Network Service Scanning (T1046) | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | AC-4(2), AC-4(21), SC-7 |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Divert, Delay | SC-26 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|--------------------------------|----------------------------|
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Network Share Discovery (T1135) | Passive Decoys (CM1104) | Misdirection | Deceive, Divert, Delay | SC-26 |
| | Conceal Resources from Discovery (CM1160) | Obfuscation, Functional Relocation of Cyber Resources | Degrade, Exert, Shorten | SC-7(16), SC-30, SC-30(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Network Sniffing (T1040) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Degrade, Preempt | SC-8(1), SC-8(4) |
| | Conceal or Randomize Network Traffic (CM1148) | Obfuscation, Contextual Unpredictability | Delay, Exert | SC-8(5), SC-30 |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Degrade, Exert | IA-2(13) |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Delay, Preempt | SI-14(3) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Password Policy Discovery (T1201) | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Peripheral Device Discovery (T1120) | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Conceal Resources from Discovery (CM1160) | Obfuscation, Functional Relocation of Cyber Resources | Degrade, Exert, Shorten | SC-7(16), SC-30, SC-30(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Permission Groups Discovery (T1069) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Scrutinize, Reveal | SI-20 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|---|---|--------------------------------|---------------------------|
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Process Discovery (T1057) | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Query Registry (T1012) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Exert, Scrutinize, Reveal | SI-20 |
| | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Remote System Discovery (T1018) | Passive Decoys (CM1104) | Misdirection | Deceive, Divert, Delay | SC-26 |
| | Conceal Resources from Discovery (CM1160) | Obfuscation, Functional Relocation of Cyber Resources | Degrade, Exert, Shorten | SC-7(16), SC-30, SC-30(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Software Discovery (T1518) | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Information Discovery (T1082) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Degrade, Exert | SC-30(4) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Location Discovery (T1614) | Present Deceptive Information (CM1101) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | Physically Relocate Resources (CM1165) | Asset Mobility | Expunge, Exert | SC-30(3) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|---|---|--------------------------------|----------------------------|
| System Network Configuration Discovery (T1016) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Degrade, Exert | SC-30(4) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Network Connections Discovery (T1049) | Conceal Resources from Discovery (CM1160) | Obfuscation, Functional Relocation of Cyber Resources | Degrade, Exert, Shorten | SC-7(16), SC-30, SC-30(5) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Owner/User Discovery (T1033) | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Exert, Scrutinize, Reveal | SI-20 |
| | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Services | Shorten | AC-12 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Service Discovery (T1007) | Lock Down Thin Nodes (CM1115) | Restriction | Preempt | SC-25 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| System Time Discovery (T1124) | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2), SI-4(4) |

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TABLE F-12: POTENTIAL EFFECTS OF CYBER RESILIENCY ON LATERAL MOVEMENT

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------------|------------------------------------|
| Exploitation of Remote Services (T1210) | Application Isolation and Sandboxing (M1048) | Predefined Segmentation | Contain, Delay, Preempt | AC-4(21), AC-6(4), CM-7(6), SC-39, |
| | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|---|------------------------------------|
| Internal Spear-Phishing (T1534) | Exploit Protection (M1050) | Integrity Checks | Delay, Exert, Detect | AC-4(8) |
| | | Behavior Validation | Detect | IR-4(13) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | AC-4(2), SC-3, SC-7, SC-7(29) |
| | Threat Intelligence Program (M1019) | Dynamic Threat Awareness | Exert, Preempt | PM-16, RA-3(3) |
| | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Endpoint Behavior Analysis (CM2003) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(11), SI-4(13) |
| Lateral Tool Transfer (T1570) | Maintain Deception Environment (CM1102) | Disinformation | Deceive | SC-30(4) |
| | | Tainting | Detect | SI-20 |
| | | Enhance User Preparedness (CM1159) | Dynamic Threat Awareness | AT-2(1), AT-2(3), AT-2(5), AT-3(3) |
| | | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(2) |
| Dynamically Restrict Traffic or Isolate Resources (T1108) | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Dynamically Restrict Traffic or Isolate Resources (CM1108) | Dynamic Reconfiguration | Contain, Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Dynamic Segmentation and Isolation | Contain, Shorten, Reduce | SC-7(20) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|--|--------------------------|-----------------------------|
| Remote Service Session Hijacking (T1563) | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |
| | | Non-Persistent Information | Preempt | SC-25 |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(24) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | AC-4(2), AC-4(21), SC-7 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Services | Expunge, Shorten | AC-12 |
| | Refresh Sessions or Connections (CM1146) | Non-Persistent Connectivity | Preempt, Shorten | SI-14(3) |
| | | Temporal Unpredictability | Preempt, Shorten | SC-23(3), SC-30(2) |
| | Account Monitoring (CM2021) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| Remote Services (T1021) | User Account Management (M1018) | Consistency Analysis, Trust-Based Privilege Management | Delay, Exert | AC-6(7) |
| | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Dynamically Restrict Traffic or Isolate Resources (CM1108) | Dynamic Reconfiguration | Contain, Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Dynamic Segmentation and Isolation | Contain, Shorten, Reduce | SC-7(20) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|---------------------------------|---------------------------|
| | Controlled Interfaces (CM1153) | Predefined Segmentation, Trust-Based Privilege Management | Negate, Exert | SC-7(15) |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(3), AU-6(5) |
| Replication Through Removable Media (T1091) | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2) |
| | Virtual Sandbox (CM1109) | Non-Persistent Services | Preempt Shorten | SI-14 |
| | | Dynamic Segmentation and Isolation | Delay, Contain | SC-7(20) |
| | Removable Device Usage Detection (CM2008) | Monitoring and Damage Assessment | Detect | CM-8(3) |
| Software Deployment Tools (T1072) | Remote Data Storage (M1029) | Predefined Segmentation, Trust-Based Privilege Management | Exert | AC-6(4) |
| | User Account Management (M1018) | Trust-Based Privilege Management | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | | Consistency Analysis | Degrade, Exert, Shorten, Reduce | AC-6(7) |
| | Isolate or Contain Selected Applications or Components (CM1133) | Trust-Based Privilege Management | Degrade, Exert, Shorten, Reduce | CM-7(6) |
| | | Predefined Segmentation | Contain | CM-7(6) |
| | Refresh Selected Applications or Components (CM1134) | Non-Persistent Services | Expunge, Shorten | SI-14(1) |
| | Monitor Trusted Parties (CM2012) | Dynamic Threat Awareness | Detect | PM-16 |
| | | Dynamic Resource Awareness | Detect | SI-4(17) |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5), AU-6(3) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--|---------------------------|
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Taint Shared Content (T1080) | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Predefined Segmentation | Contain, Divert, Delay, Degrade, Exert | SC-7(21) |
| | | Disinformation | Delay, Degrade, Exert | SC-30(4) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26, SI-3(10) |
| | Validate Data Properties (CM1137) | Integrity Checks | Negate, Detect | SI-7 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |
| Use Alternate Authentication Material (T1550) | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Exert | SC-23(3), SI-14(2), SI-21 |
| | | Temporal Unpredictability | Exert | SC-23(3) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-10 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|--|--|-------------------|---------------------------|
| | Cross-Enterprise Account Usage Analysis (CM2013) | Sensor Fusion and Analysis | Detect | AU-6(3), SI-4(16) |

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TABLE F-13: POTENTIAL EFFECTS OF CYBER RESILIENCY ON COLLECTION

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|---|---|--------------------------------|----------------------------------|
| Archive Collected Data (T1560) | Audit (M1047) | Sensor Fusion and Analysis | Detect | AU-6(5) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Audio Capture (T1123) | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Dynamically Disable or Suspend (CM1121) | Non-Persistent Connectivity | Preempt, Delay | SC-15(1) |
| | | Dynamic Reconfiguration | Preempt, Delay | AC-2(8) |
| Automated Collection (T1119) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Degrade, Preempt | SC-28(1) |
| | Remote Data Storage (M1029) | Predefined Segmentation | Delay | AU-9(2), ¹³⁶ SC-7(21) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Scrutinize, Reveal | SI-20 |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources, Temporal Unpredictability | Negate, Delay, Degrade, Exert | SC-30(3) |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Defend Against Data Mining (CM1157) | Monitoring and Damage Assessment, Trust-Based Privilege Management, Attribute-Based Usage | Delay, Degrade, Exert, Detect | AC-23 |

¹³⁶ AU-9(2) applies only to audit information.

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------------------|----------------------------|
| | | Restriction, Dynamic Privileges | | |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Clipboard Data (T1115) | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(5) |
| Data from Cloud Storage Object (T1530) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Degrade, Preempt | SC-28(1) |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Dynamic Privileges | Delay, Exert | IA-2(13), IA-10 |
| | Cloud Account Monitoring (CM2016) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |
| Data from Configuration Repository (T1602) | Encrypt Sensitive Information (M1041) | Obfuscation | Delay, Degrade, Preempt | SC-28(1) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | SC-7, SC-7(21) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Detect | SC-30(4) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Data from Information Repositories (T1213) | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Scrutinize, Reveal | SI-20 |
| | Adversarial Simulation (CM1107) | Self-Challenge | Negate | SI-19(8) |
| | Minimize Data Retention or Lifespan (CM1124) | Non-Persistent Information | Delay, Exert, Preempt | SI-14(2), SI-21 |
| | Hide Sensitive Information (CM1135) | Obfuscation | Preempt, Negate, Exert | SI-19(4) |
| | Privileged Account Monitoring (CM2017) | Monitoring and Damage Assessment | Detect | AC-6(8) |
| | Account Monitoring (CM2021) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------------------|--------------------------------|
| | Dynamic Account Management (CM1117) | Dynamic Reconfiguration | Contain, Shorten, Reduce | AC-2(6) |
| | | Dynamic Privileges | Exert, Delay | AC-2(6), AC-2(8) |
| Data from Local System (T1005) | Partition Host (CM1118) | Predefined Segmentation | Contain, Degrade, Exert | SC-2, SC-2(1), SC-32, SC-32(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Hide Sensitive Information (CM1135) | Obfuscation | Delay, Degrade, Preempt | SC-28(1) |
| Data from Network Shared Drive (T1039) | Partition Host (CM1118) | Predefined Segmentation | Contain, Degrade, Exert | SC-32 |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Scrutinize, Reveal | SI-20 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Delay, Preempt | SI-14(3) |
| | Hide Sensitive Information (CM1135) | Obfuscation | Delay, Degrade, Preempt | SC-28(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Data from Removable Media (T1025) | Monitor the File System (CM2033) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Minimize Local Functionality (CM1119) | Restriction | Preempt, Contain | SC-25 |
| | Dynamically Disable or Suspend (CM1121) | Adaptive Management, Dynamic Reconfiguration | Preempt, Delay | AC-2(8) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| Data Staged (T1074) | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources, Temporal Unpredictability | Preempt, Delay, Degrade, Exert | SC-30(3) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------|--|---|--------------------------------|----------------------------|
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| Email Collection (T1114) | Encrypt Sensitive Information (M1041) | Obfuscation | Degrade, Exert | SC-8(4) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |
| | | Tainting | Scrutinize, Reveal | SI-20 |
| | Enhanced Authentication (CM1126) | Calibrated Defense-in-Depth, Path Diversity | Delay, Exert | IA-2(13) |
| | Monitor Specific Servers (CM2034) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor Command Line Use (CM2038) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2), SI-4(4) |
| Input Capture (T1056) | Trusted Path (CM1120) ¹³⁷ | Predefined Segmentation | Contain | SC-11 |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | | Dynamic Resource Awareness | Detect | SI-4(16) |
| | Present Deceptive Information (CM1101) | Disinformation | Deceive, Delay, Degrade, Exert | SC-30(4) |

¹³⁷ Note that this mitigation applies to the capture of credentials and not to keylogging or other input capture of more general data types. Thus, it mitigates only part of the Input Capture technique.

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|-----------------------------------|--|---|--|---------------------------|
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Man-in-the-Browser (T1185) | User Account Management (M1018) | Attribute-Based Usage Restriction | Negate, Exert | AC-3(13) |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Dynamically Disable or Suspend (CM1121) | Non-Persistent Connectivity | Preempt, Delay | SC-15(1) |
| | | Dynamic Reconfiguration | Preempt, Delay | AC-2(8) |
| Man-in-the-Middle (T1557) | Disable or Remove Feature or Program (M1042) | Restriction | Negate, Exert | CM-7(2), SC-3(3) |
| | Filter Network Traffic (M1037) | Restriction | Negate, Exert | SC-3(3) |
| | Limit Access to Resource Over Network (M1035) | Trust-Based Privilege Management | Negate, Exert | AC-6(3) |
| | Network Intrusion Prevention (M1031) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(4) |
| | Network Segmentation (M1030) | Predefined Segmentation | Contain, Degrade, Exert | SC-7 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Active Deception (CM1131) | Dynamic Reconfiguration | Contain, Delay, Degrade, Exert | IR-4(2) |
| | | Adaptive Management | Contain, Delay, Degrade, Exert | AC-4(3), IR-4(3) |
| | | Misdirection | Contain, Divert, Delay, Degrade, Exert | SC-26 |
| | | Monitoring and Damage Assessment | Detect | SC-26 |
| | | Forensic and Behavioral Analysis | Detect, Scrutinize | SC-26 |
| Screen Capture (T1113) | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------------------|--|--|-----------------------|---------------------------|
| | | Dynamic Resource Awareness | Detect | SI-4(16) |
| Video Capture (T1125) | Dynamically Disable or Suspend (CM1121) | Adaptive Management, Dynamic Reconfiguration | Preempt, Delay | AC-2(8) |
| | Trusted Path (CM1120) | Predefined Segmentation | Contain, Delay, Exert | SC-11 |
| | Application- or Utility-Specific Monitoring (CM2020) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Analyze Logs (CM2005) | Monitoring and Damage Assessment | Detect | AC-2(12) |
| | | Dynamic Resource Awareness | Detect | SI-4(16) |

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TABLE F-14: POTENTIAL EFFECTS OF CYBER RESILIENCY ON COMMAND AND CONTROL

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|---|---|---------------------------------|------------------------------|
| Application Layer Protocol (T1071) | Isolate or Contain Selected Applications or Components (CM1133) | Predefined Segmentation, Dynamic Segmentation and Isolation | Preempt, Negate, Contain, Exert | CM-7(6) |
| | | Predefined Segmentation | Preempt, Negate, Contain, Exert | SC-7(21) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8), AC-4(12) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | | Predefined Segmentation | Negate, Exert | SC-46 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|--|-------------------|---------------------------|
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Communication Through Removable Media (T1092) | Operating System Configuration (M1028) | Restriction | Preempt | CM-7(2) |
| | Virtual Sandbox (CM1109) | Non-Persistent Services | Preempt Shorten | SI-14 |
| | | Dynamic Segmentation and Isolation | Delay, Contain | SC-7(20) |
| | Removable Device Usage Detection (CM2008) | Monitoring and Damage Assessment | Detect | CM-8(3) |
| Data Encoding (T1132) | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Data Obfuscation (T1001) | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | | Predefined Segmentation | Negate, Exert | SC-46 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Dynamic Resolution (T1568) | Restrict Web-Based Content (M1021) | Disinformation | Negate | SC-30(4) |
| | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--------------------------------------|--|--|-------------------|------------------------------|
| Encrypted Channel (T1573) | SSL/TLS Inspection (M1020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| Fallback Channels (T1008) | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(25) |
| | Maintain Deception Environment (CM1102) | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Misdirection | Deceive | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Refresh Sessions or Connections (CM1146) | Non-Persistent Connectivity | Degrade, Exert | SI-14(3) |
| | | Temporal Unpredictability | Degrade, Exert | SC-30(2) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| Ingress Tool Transfer (T1105) | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8), AC-4(12) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|-------------------|------------------------------|
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Multi-Stage Channels (T1104) | Refresh Sessions or Connections (CM1146) | Non-Persistent Connectivity | Degrade, Exert | SI-14(3) |
| | | Temporal Unpredictability | Degrade, Exert | SC-30(2) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8), AC-4(12) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | | Predefined Segmentation | Negate, Exert | SC-46 |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(3), AU-6(5) |
| Non-Application Layer Protocol (T1095) | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | | Predefined Segmentation | Negate, Exert | SC-46 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| Non-Standard Port (T1571) | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Network Segmentation (M1030) | Predefined Segmentation | Negate, Contain | AC-4(21), SC-7 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|--|---|-------------------|------------------------------|
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Protocol Tunneling (T1572) | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(11) |
| | | Behavior Validation | Detect | IR-4(13) |
| | | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(13) |
| Proxy (T1090) | SSL/TLS Inspection (M1020) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Defend Enclave Boundaries (CM1151) | Predefined Segmentation | Negate, Exert | AC-4(21), SC-7(21), SC-7(22) |
| | | Integrity Checks | Negate, Exert | AC-4(8) |
| | | Provenance Tracking | Negate, Exert | AC-4(17) |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | | Predefined Segmentation | Negate, Exert | SC-46 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Remote Access Software (T1219) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Lock Down Thin Nodes (CM1115) | Non-Persistent Services | Preempt | SC-25 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|----------------------------------|---|---|-------------------|---------------------------|
| | | Non-Persistent Information | Preempt | SC-25, SC-34(1) |
| | | Restriction | Preempt | SC-25 |
| | | Integrity Checks | Preempt | SC-34 |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Traffic Signaling (T1205) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Preempt, Exert | SC-10, SI-14(3) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(4) |
| Web Service (T1102) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Cross-Enterprise Behavior Analysis (CM2018) | Sensor Fusion and Analysis | Detect | AU-6(3), AU-6(5) |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |

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TABLE F-15: POTENTIAL EFFECTS OF CYBER RESILIENCY ON EXFILTRATION

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|---|--|--------------------|---------------------------|
| Automated Exfiltration (T1020) | Adversarial Simulation (CM1107) | Self-Challenge | Detect | CA-8, SC-7(10) |
| | Covert Signaling (CM1112) | Tainting | Detect, Scrutinize | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|---|---------------------------|
| | | Orchestration | Exert | AC-4(29) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Inspect and Analyze Network Traffic (CM2002) | Monitoring and Damage Assessment | Detect | AU-6, SI-4(4), SI-4(18) |
| Data Transfer Size Limits (T1030) | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(18), IR-4(13) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Exfiltration Over Alternative Protocol (T1048) | Network Intrusion Prevention (M1031) | Monitoring and Damage Assessment, Behavior Validation | Detect, Negate | SI-4(4) |
| | Network Segmentation (M1030) | Predefined Segmentation | Degrade, Delay, Exert | SC-7 |
| | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(18), IR-4(13) |
| | Exfiltration Over C2 Channel (T1041) | Network Intrusion Prevention (M1031) | Monitoring and Damage Assessment, Behavior Validation | Detect, Negate |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|---------------------------------|---------------------------|
| Exfiltration Over Network Medium (T1011) | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Delay, Preempt, Shorten, Reduce | SC-7(10), SC-10, SI-14(3) |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| Exfiltration Over Physical Medium (T1052) | Analyze Network Traffic Content (CM2041) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Minimize Duration of Connection or Session (CM1127) | Non-Persistent Connectivity | Delay, Preempt, Shorten, Reduce | SC-7(10), SC-10, SI-14(3) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Monitor Specific Files (CM2035) | Monitoring and Damage Assessment | Detect | AU-6 |
| | Disable or Remove Feature or Program (M1042) | Restriction | Exert, Preempt | CM-7(2) |
| | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------|---------------------------|
| Exfiltration Over Web Service (T1567) | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Removable Device Usage Detection (CM2008) | Monitoring and Damage Assessment | Detect | CM-8(3) |
| Scheduled Transfer (T1029) | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(18) |
| Transfer Data to Cloud Account (T1537) | Network Intrusion Prevention (M1031) | Monitoring and Damage Assessment | Detect | SI-4(4) |
| | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| Scheduled Transfer (T1029) | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Modulate Information Flows (CM1153) | Design Diversity, Replication | Negate, Exert | AC-4(27), AC-4(30) |
| | | Orchestration | Exert | AC-4(29) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | AU-6, IR-4(13) |
| | Analyze Outgoing Traffic Patterns (CM2042) | Monitoring and Damage Assessment, Behavior Validation | Detect | SI-4(18), IR-4(13) |
| Transfer Data to Cloud Account (T1537) | Covert Signaling (CM1112) | Tainting | Detect, Reveal | SI-20 |
| | Present Decoy Data (CM1113) | Disinformation, Misdirection | Deceive, Degrade | SC-30(4), SC-26 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|---|---|--------------------|---------------------------|
| | | Tainting | Detect, Scrutinize | SI-20 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Cloud Account Monitoring (CM2016) | Monitoring and Damage Assessment, Behavior Validation | Detect | AC-2(12) |

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TABLE F-16: POTENTIAL EFFECTS OF CYBER RESILIENCY ON IMPACT

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|--|---|--------------------|---------------------------|
| Account Access Removal (T1531) | Use Alternate Communications (CM1140) | Path Diversity | Shorten, Reduce | AC-7(4), SC-47 |
| | Dynamic Account Management (CM1117) | Dynamic Privilege, Dynamic Reconfiguration | Shorten, Reduce | AC-2(6) |
| | | Dynamic Reconfiguration | Shorten, Reduce | AC-2(8) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Data Destruction (T1485) | Data Backup (M1053) | Protected Backup and Restore | Shorten, Reduce | CP-9 |
| | | Replication | Shorten, Reduce | CP-9(6) |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources | Preempt | SC-30(3) |
| | | Temporal Unpredictability | Preempt, Exert | SC-30(3) |
| | Validate Data Quality (CM1130) | Integrity Checks | Detect | SA-9(7), SI-7(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|---|---|--------------------------|---------------------------|
| T1486 | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| | Switch to Alternative Data Sources (CM1138) | Information Diversity | Reduce, Shorten | SI-22 |
| | | Dynamic Reconfiguration | Contain, Reduce, Shorten | IR-4(2) |
| | Dynamically Reprovision (CM1139) | Adaptive Management | Shorten, Reduce | AC-4(3) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | Reconstruct Compromised Assets (CM1141) | Information Diversity | Exert, Reduce | SI-22 |
| | | Fragmentation | Exert, Reduce | SI-23 |
| | | Replication | Exert, Reduce | SC-36 |
| | | Dynamic Reconfiguration | Reduce, Shorten | IR-4(9) |
| | Switch to Protected Hot Shadow (CM1142) | Replication | Shorten, Reduce | CP-9(6) |
| | | Predefined Segmentation | Shorten, Reduce | AC-4(2) |
| | | Integrity Checks | Shorten, Reduce | AC-4(8) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| T1486 | Data Backup (M1053) | Protected Backup and Restore | Shorten, Reduce | CP-9, CP-9(8) |
| | | Replication | Shorten, Reduce | CP-9(6) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Fragment Information (CM1114) | Fragmentation | Delay, Exert | SI-23 |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources | Preempt | SC-30(3) |
| | | Temporal Unpredictability | Preempt, Exert | SC-30(3) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|----------------------------------|---|---|--------------------------|-----------------------------|
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| | Switch to Alternative Data Sources (CM1138) | Information Diversity | Reduce, Shorten | SI-22 |
| | | Dynamic Reconfiguration | Contain, Reduce, Shorten | IR-4(2) |
| | Dynamically Reprovision (CM1139) | Adaptive Management | Shorten, Reduce | AC-4(3) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | Reconstruct Compromised Assets (CM1141) | Information Diversity | Exert, Reduce | SI-22 |
| | | Fragmentation | Exert, Reduce | SI-23 |
| | | Replication | Exert, Reduce | SC-36 |
| | | Dynamic Reconfiguration | Reduce, Shorten | IR-4(9) |
| | Switch to Protected Hot Shadow (CM1142) | Replication | Shorten, Reduce | CP-9(6) |
| | | Predefined Segmentation | Shorten, Reduce | AC-4(2) |
| | | Integrity Checks | Shorten, Reduce | AC-4(8) |
| | | Dynamic Reconfiguration, | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| Data Manipulation (T1565) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Exert | AC-4(2), AC-4(21), SC-7(29) |
| | Encrypt Sensitive Information (M1041) | Obfuscation | Degrade, Exert | SC-28(1) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Trusted Path (CM1120) | Predefined Segmentation | Negate, Contain | SC-11 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------|---|---|--------------------------|---------------------------|
| Defacement (T1491) | Validate Data Properties (CM1137) | Integrity Checks | Delay, Degrade, Exert | SI-7, SI-7(1) |
| | | Calibrated Defense-in-Depth | Delay, Degrade | PL-8(1) |
| | Switch to Alternative Data Sources (CM1138) | Information Diversity | Reduce, Shorten | SI-22 |
| | | Dynamic Reconfiguration | Contain, Reduce, Shorten | IR-4(2) |
| | Validate Output Data (CM1155) | Integrity Checks | Detect, Reduce | SI-15 |
| | Analyze File Contents (CM2006) | Forensic and Behavioral Analysis | Detect | SR-10 |
| | Data Backup (M1053) | Protected Backup and Restore | Shorten, Reduce | CP-9 |
| | | Replication | Shorten, Reduce | CP-9(6) |
| | | Protected Backup and Restore, Obfuscation, Integrity Checks | Exert | CP-9(8) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources | Preempt | SC-30(3) |
| | | Temporal Unpredictability | Preempt, Exert | SC-30(3) |
| | Validate Data Quality (CM1130) | Integrity Checks | Detect | SA-9(7), SI-7(1) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |
| Disk Wipe (T1561) | Data Backup (M1053) | Protected Backup and Restore | Shorten, Reduce | CP-9 |
| | | Replication | Shorten, Reduce | CP-9(6) |
| | Passive Decoys (CM1104) | Misdirection | Deceive, Negate, Contain | SC-26 |
| | Dynamic Data Location (CM1116) | Functional Relocation of Cyber Resources | Preempt | SC-30(3) |
| | | Temporal Unpredictability | Preempt, Exert | SC-30(3) |
| | Host Event Detection (CM2007) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13), SI-4(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|---|--------------------------|---------------------------|
| T1053.01 - Identify and Mitigate Mission Impact | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| | Switch to Alternative Data Sources (CM1138) | Information Diversity | Reduce, Shorten | SI-22 |
| | | Dynamic Reconfiguration | Contain, Reduce, Shorten | IR-4(2) |
| | Dynamically Reprovision (CM1139) | Adaptive Management | Shorten, Reduce | AC-4(3) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | Reconstruct Compromised Assets (CM1141) | Protected Backup and Restore | Exert, Reduce | CP-9 |
| | | Information Diversity | Exert, Reduce | SI-22 |
| | | Fragmentation | Exert, Reduce | SI-23 |
| | | Replication, Distributed Functionality | Exert, Reduce | SC-36 |
| | | Dynamic Reconfiguration | Reduce, Shorten | IR-4(9) |
| T1053.02 - Identify and Mitigate System Impact | Switch to Protected Hot Shadow (CM1142) | Replication | Shorten, Reduce | CP-9(6) |
| | | Predefined Segmentation | Shorten, Reduce | AC-4(2) |
| | | Integrity Checks | Shorten, Reduce | AC-4(8) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | Switch to Alternate System or Component (CM1143) | Architectural Diversity | Shorten, Reduce | SC-29 |
| | | Design Diversity | Shorten, Reduce | SA-17(9) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---|--|--|---------------------------------|----------------------------|
| Endpoint Denial of Service (T1499) | Defend Failover and Recovery (CM1145) | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | | Adaptive Management, Dynamic Reconfiguration, Orchestration | Shorten, Reduce, Exert | IR-4(3) |
| | | Functional Relocation of Sensors | Detect | SC-48, SC-48(1) |
| | | Dynamic Reconfiguration, Functional Relocation of Sensors | Detect | IR-4(2) |
| | | Dynamic Segmentation and Isolation | Shorten, Reduce, Contain, Exert | SC-7(20) |
| | | Mission Dependency and Status Visualization | Detect | SI-4(1) |
| | | Dynamic Privileges | Contain, Exert | AC-2(6) |
| | Filter Network Traffic (M1037) | Adaptive Management | Degrade, Reduce | AC-4(3), SC-7(11) |
| | Maintain Deception Environment (CM1102) | Misdirection | Deceive, Divert | SC-26 |
| | | Monitoring and Damage Assessment, Forensic and Behavioral Analysis | Detect | SC-26 |
| | | Predefined Segmentation | Negate, Contain | SC-7(21) |
| | | Disinformation | Deceive | SC-30(4) |
| | Dynamically Restrict Traffic or Isolate Resources (CM1108) | Dynamic Resource Allocation, Adaptive Management | Degrade, Reduce | AU-5(3), IR-4(2), SC-7(20) |
| | Partition Host (CM1118) | Predefined Segmentation | Degrade, Reduce | SC-2, SC-32 |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------------------------|--|---|------------------------|---------------------------|
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| Firmware Corruption (T1495) | Boot Integrity (M1046) | Integrity Checks | Detect | SI-7, SI-7(9), SI-7(10) |
| | Privileged Account Management (M1026) | Trust-Based Privilege Management | Negate, Exert | AC-6(5), CM-5(5) |
| | Switch to Alternate System or Component (CM1143) | Architectural Diversity | Shorten, Reduce | SC-29 |
| | | Design Diversity | Shorten, Reduce | SA-17(9) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | | Activate Alternate (CM1144) | Shorten, Reduce, Exert | SC-29 |
| | | Design Diversity | Shorten, Reduce, Exert | SA-17(9) |
| | | Specialization | Shorten, Reduce, Exert | SA-20, SA-23 |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | Defend Failover and Recovery (CM1145) | Adaptive Management, Dynamic Reconfiguration, Orchestration | Shorten, Reduce, Exert | IR-4(3) |
| | | Functional Relocation of Sensors | Detect | SC-48, SC-48(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|--|---|---------------------------------|---------------------------|
| Inhibit System Recovery (T1490) | | Dynamic Segmentation and Isolation | Shorten, Reduce, Contain, Exert | SC-7(20) |
| | | Mission Dependency and Status Visualization | Detect | SI-4(1) |
| | | Dynamic Privileges | Contain, Exert | AC-2(6) |
| | Hardware-Based Protection of Firmware (CM1154) | Integrity Checks | Negate, Preempt | SC-51 |
| | Data Backup (M1053) | Protected Backup and Restore | Shorten, Reduce | CP-9 |
| | | Replication | Shorten, Reduce | CP-9(6) |
| | | Protected Backup and Restore, Obfuscation, Integrity Checks | Exert | CP-9(8) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13) |
| | Monitor the File System (CM2033) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | | Sensor Fusion and Analysis | Detect | SI-4(24) |
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| | Switch to Alternate System or Component (CM1143) | Architectural Diversity | Shorten, Reduce, Exert | SC-29 |
| | | Design Diversity | Shorten, Reduce, Exert | SA-17(9) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | Activate Alternate (CM1144) | Architectural Diversity | Shorten, Reduce, Exert | SC-29 |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|--|---|---|---------------------------------|----------------------------|
| | <p>Defend Failover and Recovery (CM1145)</p> | Design Diversity | Shorten, Reduce, Exert | SA-17(9) |
| | | Specialization | Shorten, Reduce, Exert | SA-20, SA-23 |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |
| | | Adaptive Management, Dynamic Reconfiguration, Orchestration | Shorten, Reduce, Exert | IR-4(3) |
| | | Functional Relocation of Sensors | Detect | SC-48, SC-48(1) |
| | | Dynamic Reconfiguration, Functional Relocation of Sensors | Detect | IR-4(2) |
| | | Dynamic Segmentation and Isolation | Shorten, Reduce, Contain, Exert | SC-7(20) |
| | | Mission Dependency and Status Visualization | Detect | SI-4(1) |
| | | Dynamic Privileges | Contain, Exert | AC-2(6) |
| Network Denial of Service (T1498) | <p>Filter Network Traffic (M1037)</p> | Adaptive Management | Degrade, Reduce | AC-4(3) |
| | | Provenance Tracking | Degrade, Reduce | SC-7(11) |
| | <p>Dynamically Restrict Traffic or Isolate Resources (CM1108)</p> | Dynamic Resource Allocation, Adaptive Management | Degrade, Reduce | AU-5(3), IR-4(2), SC-7(20) |
| | <p>Monitor Network Usage (CM2047)</p> | Monitoring and Damage Assessment, Behavior Validation | Detect | IR-4(13) |
| | <p>Switch to Alternate System or Component (CM1143)</p> | Replication | Degrade, Reduce | SC-22 |
| | <p>Defend Against DoS (CM1147)</p> | Dynamic Resource Allocation, Surplus Capacity | Shorten, Reduce | SC-5(2) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|---------------------------------------|--|---|--------------------------|------------------------------|
| | | Monitoring and Damage Assessment | Detect | SC-5(3) |
| Resource Hijacking (T1496) | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Monitor Network Usage (CM2047) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(11), SI-4(13) |
| | Dynamically Reprovision (CM1139) | Dynamic Reconfiguration | Shorten | IR-4(2) |
| | | Dynamic Segmentation and Isolation | Reduce | SC-7(20) |
| | Dynamically Disable or Suspend (CM1121) | Adaptive Management | Preempt, Delay | SC-15(1) |
| | | Dynamic Reconfiguration | Preempt, Delay | AC-2(8) |
| Service Stop (T1489) | Network Segmentation (M1030) | Predefined Segmentation | Contain, Shorten, Reduce | IR-4(14), SC-3, SC-7(29) |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13) |
| | Monitor Platform Status (CM2044) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |
| System Shutdown/Reboot (T1529) | Passive Decoys (CM1104) | Misdirection | Deceive, Detect | SC-26 |
| | Process Monitoring (CM2015) | Monitoring and Damage Assessment | Detect | IR-4(13), SI-4(2) |
| | Perform Mission Damage Assessment (CM1122) | Mission Dependency and Status Visualization | Detect, Scrutinize | CP-2(8), RA-9 |
| | | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | Detect, Scrutinize | SI-4(1) |
| | | Integrity Checks | Detect, Scrutinize | SI-7, SI-7(1) |

| ATT&CK Technique | Mitigation or Candidate Mitigation | Cyber Resiliency Implementation Approaches | Potential Effects | Cyber Resiliency Controls |
|------------------|--|---|------------------------|---------------------------|
| | Switch to Alternate System or Component (CM1143) | Architectural Diversity | Shorten, Reduce, Exert | SC-29 |
| | | Design Diversity | Shorten, Reduce, Exert | SA-17(9) |
| | | Dynamic Reconfiguration | Shorten, Reduce | IR-4(2) |
| | | Dynamic Reconfiguration, Adaptive Management, Orchestration | Shorten, Reduce | CP-2(5) |

3131

3132 F.2.4 Candidate Mitigations

3133 Neither a cyber resiliency implementation approach nor a security control *per se* has a potential
 3134 effect on an adversary TTP or other threat event. Rather, it is the way the cyber resiliency
 3135 approaches and controls are implemented and used that can produce an effect. In the Potential
 3136 Effects on Threat Events (PETE) analysis for ATT&CK, descriptions of potential uses of cyber
 3137 resiliency implementation approaches and controls are captured via ATT&CK mitigations or
 3138 candidate mitigations. A candidate mitigation is a mitigation, defined in the context of ATT&CK
 3139 and given an identifier of the form CM#####, which has been derived from engineering analysis
 3140 rather than from a curated data set. It is designated as a “candidate” to differentiate it from the
 3141 mitigations in the ATT&CK knowledge base. A mitigation or candidate mitigation is given an
 3142 identifier and a name (a short phrase). These identifiers and names appear in the mapping
 3143 tables in [Section F.2.3](#).

3144 Tables F-17 through F-19 define the candidate mitigations.¹³⁸ The structure of a candidate
 3145 mitigation is similar to that of mitigations described in the ATT&CK knowledge base (i.e., an
 3146 identifier, a name, a brief general description, and the cyber resiliency approaches and controls
 3147 needed to implement the mitigation). The description tailored to individual techniques serves to
 3148 improve consistency in the analysis of how defender actions or decisions could affect adversary
 3149 activities as described in ATT&CK. However, because the candidate mitigations are not part of
 3150 the ATT&CK knowledge base, the identification and numbering scheme is different—that is,
 3151 candidate mitigation identifiers begin with “CM.”

3152 [Table F-17](#) identifies candidate mitigations that are intended to have an effect other than
 3153 Expose, with identifiers of the form CM11##. [Table F-18](#) identifies candidate mitigations that are
 3154 solely intended to have the Expose effect, with identifiers of the form CM20##. These candidate
 3155 mitigations are derived from the Detection descriptions in ATT&CK. Many of the Detection
 3156 mitigations use the same cyber resiliency controls, particularly IR-4(13) and SI-4(2). However, as
 3157 indicated by the different names of the candidate mitigations, the implementation of those

¹³⁸ See [Bodeau21](#) for definitions of ATT&CK mitigations.

3158 controls and the use of as-implemented capabilities can vary significantly. [Table F-19](#) identifies
 3159 candidate mitigations that could increase the effectiveness of other candidate mitigations or
 3160 ATT&CK mitigations, with identifiers of the form CM13##.¹³⁹ Since these candidate mitigations
 3161 have no direct effect on threat events, they are not included in the PETE analysis for ATT&CK.
 3162 For each candidate mitigation, one or more cyber resiliency controls (i.e., base controls or
 3163 control enhancements as listed in [Table E-1](#)) are identified, and the cyber resiliency approaches
 3164 associated with the identified set of controls are also identified. A high-level description of the
 3165 candidate mitigation is also given.

3166 The controls (and associated cyber resiliency approaches) used by a candidate mitigation to
 3167 mitigate different threat events can vary. Thus, for a given threat event, only a subset of the
 3168 controls identified in Tables F-17 through F-19 could be used. In addition, the effects of a
 3169 mitigation or candidate mitigation on different threat events can vary, depending on the details
 3170 of the threat events and how the mitigation or candidate mitigation is used.¹⁴⁰

3171 **TABLE F-17: CANDIDATE MITIGATIONS TO REDIRECT, PRECLUDE, IMPEDE, OR LIMIT THREAT EVENTS**

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---------------------------------|--|---|---|
| CM1101 | Present Deceptive Information | Present deceptive information about systems, data, processes, and users. Monitor uses or search for presence of that information. | Disinformation, Tainting | SC-30(4), SI-20 |
| CM1102 | Maintain Deception Environment | Maintain a distinct subsystem or a set of components specifically designed to be the target of malicious attacks for detecting, deflecting, and analyzing such attacks. | Monitoring and Damage Assessment, Forensic and Behavioral Analysis, Misdirection, Disinformation, Predefined Segmentation | SC-7(21), SC-26, SC-30(4) |
| CM1103 | Detonation Chamber | Use a dynamic execution environment to handle potentially harmful incoming data. | Forensic and Behavioral Analysis, Misdirection, Predefined Segmentation | SC-44 |
| CM1104 | Passive Decoys | Use a factitious system or resource to decoy adversary attacks away from operational resources to increase the adversary's workload, or to observe adversary activities. | Misdirection, Architectural Diversity | SC-26, SC-29 |
| CM1105 | Component Provenance Validation | Validate the provenance of system components. | Integrity Checks, Provenance Tracking | SR-4, SR-4(1), SR-4(2), SR-4(3), SR-4(4), SR-11 |
| CM1106 | Supply Chain Diversity | Provide multiple distinct supply chains for system components. | Supply Chain Diversity | PL-8(2), SR-3(1), SR-3(2) |

¹³⁹ Gaps in numbering of candidate mitigations are artifacts of the analysis process, and do not indicate that additional candidate mitigations are defined elsewhere.

¹⁴⁰ See [\[Bodeau21\]](#) for descriptions specific to individual ATT&CK techniques.

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---|---|---|---|
| CM1107 | Adversarial Simulation | Simulate adversary activities to test the effectiveness of system protections and detection mechanisms. | Self-Challenge | AT-2(1), AT-3(3), CA-8, CA-8(2), SC-7(10), SI-19(8) |
| CM1108 | Dynamically Restrict Traffic or Isolate Resources | Dynamically reconfigure networks to restrict network traffic or isolate resources. | Dynamic Resource Allocation, Adaptive Management, Dynamic Reconfiguration, Dynamic Segmentation and Isolation | AU-5(3), IR-4(2), SC-7(20) |
| CM1109 | Virtual Sandbox | Use virtualization to create a controlled execution environment, which is expunged after execution terminates. | Non-Persistent Services, Dynamic Segmentation and Isolation | SC-7(20), SI-14 |
| CM1110 | Application- or Utility-Specific Data Removal | Analyze files and data structures specific to an application or utility for anomalies, and delete them. | Monitoring and Damage Assessment, Integrity Checks, Dynamic Reconfiguration | IR-4(2), IR-4(13), SI-4(2), SI-7(1), SI-7(7) |
| CM1111 | Execution Restriction | Restrict the sources of executables, the locations in which execution can occur, or implement other constraints on execution access. | Attribute-Based Usage Restriction | AC-3(12), AC-3(13) |
| CM1112 | Covert Signaling | Use hidden logic to enable exfiltrated data to signal its location, or embed hidden data that can be the subject of a search. | Tainting | SI-20 |
| CM1113 | Present Decoy Data | Present plausible but factitious data assets to attract the adversary. Monitor uses of those assets, or search for the presence of decoy information. | Disinformation, Misdirection, Tainting | SC-26, SC-30(4), SI-20 |
| CM1114 | Fragment Information | Fragment information, and distribute it across multiple locations. | Fragmentation | SI-23 |
| CM1115 | Lock Down Thin Nodes | Minimize local functionality and disallow writable storage. | Non-Persistent Services, Non-Persistent Information, Restriction, Integrity Checks | SC-25, SC-34, SC-34(1) |
| CM1116 | Dynamic Data Location | Dynamically move data resources. | Functional Relocation of Cyber Resources, Temporal Unpredictability | SC-30(3) |
| CM1117 | Dynamic Account Management | Dynamically update an account's authorizations or privileges. | Dynamic Privileges, Dynamic Reconfiguration | AC-2(6), AC-2(8) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|--|--|---|---------------------------------------|
| CM1118 | Partition Host | Partition a host (e.g., server, endpoint system) into separate logical domains. | Predefined Segmentation | SC-2, SC-2(1), SC-32, SC-32(1) |
| CM1119 | Minimize Local Functionality | Construct or configure systems or applications to minimize their inherent functionality. | Restriction | CM-7(2), SC-25 |
| CM1120 | Trusted Path | Provide an isolated communications path between the user and security functions. | Predefined Segmentation | SC-11 |
| CM1121 | Dynamically Disable or Suspend | Terminate processes or disable capabilities upon triggering conditions. | Adaptive Management, Dynamic Reconfiguration | AC-2(8), SC-15(1) |
| CM1122 | Perform Mission Damage Assessment | Determine the mission consequences of adversary activities (e.g., which resources can be relied on; how quickly, how completely, and with what confidence mission-essential services, data, and communications can be restored from backups or alternative resources). | Sensor Fusion and Analysis, Mission Dependency and Status Visualization, Integrity Checks | CP-2(8), RA-9, SI-4(1), SI-7, SI-7(1) |
| CM1123 | Active Decoys | Use one or more factitious systems or other resources to identify malicious sites, interact with the adversary, actively probe for malicious code, and observe adversary TTPs. | Forensic and Behavioral Analysis, Misdirection, Dynamic Segmentation and Isolation | SC-26, SC-35, SC-44 |
| CM1124 | Minimize Data Retention or Lifespan | Minimize the lifespan or retention of data, and ensure that deleted data cannot be retrieved. | Non-Persistent Information, Temporal Unpredictability | SC-23(3), SI-14(2), SI-21 |
| CM1125 | Authenticate Devices | Authenticate a device before establishing a connection to it. | Obfuscation, Integrity Checks | IA-3(1) |
| CM1126 | Enhanced Authentication | Use situation-specific, risk-adaptive, or out-of-band authentication. | Adaptive Management, Calibrated Defense-in-Depth, Architectural Diversity, Design Diversity, Path Diversity, Dynamic Privileges | IA-2(13), IA-10, CP-13, SC-47 |
| CM1127 | Minimize Duration of Connection or Session | Minimize the time period for which a connection remains open or a session remains active, requiring reauthorization to reestablish connectivity. | Non-Persistent Services, Non-Persistent Connectivity | AC-12, SC-7(10), SC-10, SI-14(3) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|--|---|--|--|
| CM1128 | Design Diversity | Use multiple designs to implement the same functionality. | Design Diversity | SA-17(9) |
| CM1129 | Check Policy Consistency | Ensure that policies are applied consistently across systems, applications, and services. | Consistency Analysis | CA-7(5) |
| CM1130 | Validate Data Quality | Validate data quality (e.g., integrity, consistency, correctness). | Integrity Checks | SA-9(7), SI-7(1) |
| CM1131 | Active Deception | Maintain an internal deception environment, divert suspicious traffic to that environment, and interact with and analyze behavior to determine whether it is malicious and to whether investigate adversary TTPs. | Dynamic Reconfiguration, Adaptive Management, Misdirection, Monitoring and Damage Assessment, Forensic and Behavioral Analysis | AC-4(3), IR-4(2), IR-4(3), SC-7(21), SC-26, SC-30(4), SI-3(10) |
| CM1132 | Quarantine or Delete Suspicious Files | Move and make inaccessible or delete suspicious files. | Provenance Tracking, Dynamic Segmentation and Isolation, Non-Persistent Information | SR-4(3), CM-7(6), SI-14, SI-14(2) |
| CM1133 | Isolate or Contain Selected Applications or Components | Isolate or contain (e.g., using internal firewalls or virtual environments) selected applications or components based on risk profiles. | Trust-Based Privilege Management, Predefined Segmentation, Dynamic Segmentation and Isolation | CM-7(6), SC-7(21) |
| CM1134 | Refresh Selected Applications or Components | Refresh software, firmware, or data from a trusted source. | Non-Persistent Services, Non-Persistent Information | SI-14(1), SI-14(2) |
| CM1135 | Hide Sensitive Information | Conceal (e.g., via encryption or data hiding) or remove sensitive information (including metadata). | Obfuscation | SC-28(1), SI-19(4) |
| CM1136 | Identify External Malware | Identify and redirect malware found on external systems. | Monitoring and Damage Assessment, Forensic and Behavioral Analysis, Misdirection, Dynamic Segmentation and Isolation | SC-35 |
| CM1137 | Validate Data Properties | Validate data properties (including binaries, metadata, and cryptographic bindings) to defend against modification or fabrication. | Integrity Checks, Calibrated Defense-in-Depth | PL-8(1), SC-16(1), SC-16(3), SI-7, SI-7(1) |
| CM1138 | Switch to Alternative Data Sources | Switch to one or more alternative data sources to ensure adequate data quality or rebuild destroyed data. | Information Diversity, Dynamic Reconfiguration | SI-22, IR-4(2) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---|---|--|---|
| CM1139 | Dynamically Reprovision | Reconfigure or reallocate resources to route around damage. | Adaptive Management, Dynamic Reconfiguration, Dynamic Segmentation and Isolation | AC-4(3), IR-4(2), SC-7(20) |
| CM1140 | Use Alternate Communications | Use alternative communications paths. | Path Diversity | AC-7(4), SC-47 |
| CM1141 | Reconstruct Compromised Assets | Reconstruct assets (e.g., files, software components) that have been damaged, destroyed, or modified in a way that makes them suspect. | Information Diversity, Fragmentation, Distributed Functionality, Protected Backup and Restore, Replication, Dynamic Reconfiguration | SC-36, SI-22, SI-23, IR-4(9), CP-9 |
| CM1142 | Switch to Protected Hot Shadow | Switch (failover) to a duplicate system in a protected enclave that, subject to additional quality controls on data and software updates, mirrors the system that has been compromised. | Dynamic Reconfiguration, Adaptive Management, Orchestration, Replication, Predefined Segmentation, Integrity Checks | AC-4(2), AC-4(8), CP-2(5), CP-9(6), IR-4(2) |
| CM1143 | Switch to Alternate System or Component | Switch (failover) to another system or system component that provides approximately the same functionality in a different way. | Architectural Diversity, Design Diversity, Dynamic Reconfiguration, Adaptive Management, Orchestration, Replication | CP-2(5), IR-4(2), SA-17(9), SC-22, SC-29 |
| CM1144 | Activate Alternate | Activate an alternate system or system component (e.g., from a war-time reserve) that provides approximately the same function in a novel or specialized way, and failover. | Architectural Diversity, Design Diversity, Dynamic Reconfiguration, Adaptive Management, Orchestration, Specialization | CP-2(5), IR-4(2), SA-17(9), SA-20, SA-23, SC-29 |
| CM1145 | Defend Failover and Recovery | Increase sensor activity and restrict privileges to defend against an adversary taking advantage of failover or recovery activities. | Adaptive Management, Dynamic Reconfiguration, Orchestration, Functional Relocation of Sensors, Dynamic Segmentation and Isolation, Mission Dependency and Status Visualization, Dynamic Privileges | AC-2(6), IR-4(2), IR-4(3), SC-7(20), SC-48, SC-48(1), SI-4(1) |
| CM1146 | Refresh Sessions or Connections | Terminate and re-establish sessions or network connections unpredictably to disrupt adversary use. | Non-Persistent Connectivity, Temporal Unpredictability | SC-23(3), SC-30(2), SI-14(3) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---|--|---|--|
| CM1147 | Defend Against DoS | Adapt to reduce the impacts of denial-of-service attacks. | Dynamic Resource Allocation, Surplus Capacity, Monitoring and Damage Assessment | SC-5(2), SC-5(3) |
| CM1148 | Conceal or Randomize Network Traffic | Conceal (via encryption or insertion of fabricated traffic) or randomize network traffic patterns. | Obfuscation, Contextual Unpredictability | SC-8(5), SC-30 |
| CM1149 | Lock Down Visibility or Access | Restrict the visibility of or access to data based on the nature or attributes of that data. | Attribute-Based Usage Restriction | AC-3(11) |
| CM1150 | Dynamically Relocate and Refresh Processing | Suspend a process and re-instantiate it in a different location. | Functional Relocation of Cyber Resources, Non-Persistent Services | SC-30(3), SI-14(1) |
| CM1151 | Defend Enclave Boundaries | Maintain distinct enclaves based on security characteristics, and use stringent filtering to defend the enclave boundary. | Predefined Segmentation, Integrity Checks, Provenance Tracking | AC-4(8), AC-4(12), AC-4(17), AC-4(21), SC-7(21), SC-7(22), SC-46 |
| CM1152 | Defend Against Memory Attacks | Provide defenses against attacks against system memory. | Synthetic Diversity, Temporal Unpredictability | SI-16 |
| CM1153 | Modulate Information Flows | Use controlled interfaces and communications paths to provide access to risky capabilities or to filter communications between enclaves. | Orchestration Design Diversity, Replication, Trust-Based Privilege Management, Predefined Segmentation | AC-4(27), AC-4(29), AC-4(30), SC-7(15), SC-46 |
| CM1154 | Hardware-Based Protection of Firmware | Use hardware-based protections for firmware. | Integrity Checks | SC-51 |
| CM1155 | Validate Output Data | Validate information output from processes or applications against defined criteria. | Integrity Checks | SI-15 |
| CM1156 | Physically Relocate Resources | Physically move resources (e.g., storage devices, servers, end-user devices), with concomitant changes to network location. | Asset Mobility | SC-30(3) |
| CM1157 | Defend Against Data Mining | Enforce access restrictions and provide alerting to defend against data mining. | Monitoring and Damage Assessment, Trust-Based Privilege Management, Attribute-Based Usage Restriction, Dynamic Privileges | AC-23 |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|------------------------------------|--|---|---|
| CM1158 | Defend Audit Data | Provide mechanisms to protect audit data from modification or observation. | Integrity Checks | AU-9(1), AU-9(2), AU-9(3), AU-9(6) |
| CM1159 | Enhance User Preparedness | Keep users, administrators, and operators aware of existing and emerging threats and attack techniques that they can counter in practice. | Dynamic Threat Awareness, Self-Challenge | AT-2(1), AT-2(3), AT-2(5), AT-3(3) |
| CM1160 | Conceal Resources from Discovery | Protect network addresses of system components that are part of managed interfaces from discovery through common tools and techniques, such as hiding or relocation. | Obfuscation, Functional Relocation of Cyber Resources | SC-7(16), SC-30, SC-30(5) |
| CM1161 | Collaborate to Counter Adversaries | Collaborate with other entities to counter adversary activities. | Disinformation, Tainting, Dynamic Threat Awareness | PM-16, SC-30(4), SI-20 |
| CM1162 | Restrict Supply Chain Exposures | Limit an adversary's ability to determine or manipulate the organization's cyber supply chain. | Obfuscation, Disinformation, Self-Challenge, Supply Chain Diversity | PM-30(1), SI-4(10), SR-3(2), SR-5, SR-6(1), SR-7, SR-11 |
| CM1163 | Redefine System | Redefine the system in terms of components, interfaces, and dependencies. | Orchestration, Architectural Diversity, Supply Chain Diversity, Evolvability, Replication | IR-4(10), SC-27, SC-29, SR-5(1) |
| CM1164 | Calibrate Administrative Access | Configure administrator access to resources based on active defense strategies. | Attribute-Based Usage Restriction, Trust-Based Privilege Management, Restriction | AC-6, AC-6(5), CM-7(2) |
| CM1165 | Physically Relocate Resources | Physically move resources (e.g., storage devices, servers, end-user devices), with concomitant changes to network location. | Asset Mobility | SC-30(3) |

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TABLE F-18: CANDIDATE MITIGATIONS TO EXPOSE THREAT EVENTS

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|-------------------------------------|---|----------------------------------|----------------------------|
| CM2002 | Inspect and Analyze Network Traffic | Analyze network traffic for unusual data flows. Traffic inspection and analysis can be performed at the enterprise boundary, at internal boundaries between enclaves, or within enclaves. | Monitoring and Damage Assessment | IR-4(13), SI-4(2), SI-4(4) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---|--|--|--|
| CM2003 | Endpoint Behavior Analysis | Analyze the behavior of endpoint (i.e., end-user, client) systems for anomalous behavior. | Monitoring and Damage Assessment, Behavior Validation | AC-2(12) |
| CM2004 | Monitor Logs | Monitor system and application logs for anomalous or suspicious behavior. | Monitoring and Damage Assessment, Behavior Validation | AU-6, IR-4(13), SI-4(2), SI-4(11) |
| CM2005 | Analyze Logs | Analyze logs (individually or with some correlation across logs) for anomalous or suspicious patterns of behavior. | Monitoring and Damage Assessment, Sensor Fusion and Analysis, Dynamic Resource Analysis, Behavior Validation | AC-2(12), SI-4(13), SI-4(16) |
| CM2006 | Analyze File Contents | Analyze the contents of specific files or types of files for suspicious contents. | Forensic and Behavioral Analysis | SR-10 |
| CM2007 | Host Event Detection | Detect anomalous or unauthorized events on hosts (e.g., servers, endpoint systems). | Monitoring and Damage Assessment, Behavior Validation | CM-8(3), IR-4(13), SI-4(2) |
| CM2008 | Removable Device Usage Detection | Detect anomalous or unauthorized events involving the use of removable devices. | Monitoring and Damage Assessment | CM-8(3) |
| CM2009 | Software Integrity Check | Perform integrity checks (e.g., using checksums, hashes, or digital signatures) on software, software certificates, or metadata. | Integrity Checks, Provenance Tracking | SI-7, SI-7(1), SI-7(6), CM-14, SR-4(3) |
| CM2010 | Software Stress Testing | Perform software stress testing (e.g., using out-of-bounds input values) prior to installation. | Self-Challenge | SR-6(1) |
| CM2011 | Physical Inspection | Perform a physical inspection of hardware components for indicators of tampering. | Integrity Checks | SR-9, SR-10 |
| CM2012 | Monitor Trusted Parties | Monitor the behavior and status (e.g., change in ownership) of second or third parties. | Dynamic Resource Awareness, Dynamic Threat Awareness, Behavior Validation, Provenance Tracking | PM-16, PM-30(1), SI-4(17) |
| CM2013 | Cross-Enterprise Account Usage Analysis | Analyze user account usage across the enterprise for anomalies or suspicious behavior. | Sensor Fusion and Analysis | AU-6(3), SI-4(16) |
| CM2014 | Process Analysis | Analyze process attributes or behavior for indications of unusual, unauthorized, or suspicious use. | Monitoring and Damage Assessment | IR-4(13), SI-4(2) |
| CM2015 | Process Monitoring | Monitor the behavior of processes for indications of unusual, unauthorized, or suspicious use. | Monitoring and Damage Assessment, Behavior Validation | AU-6, IR-4(13), SI-4(2) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|---|---|---|-----------------------------|
| CM2016 | Cloud Account Monitoring | Monitor activity associated with cloud accounts for indications of unusual, unauthorized, or suspicious use. | Monitoring and Damage Assessment, Behavior Validation | AC-2(12) |
| CM2017 | Privileged Account Monitoring | Monitor and analyze activity associated with privileged accounts for indications of unusual or suspicious use. | Monitoring and Damage Assessment | AC-6(8) |
| CM2018 | Cross-Enterprise Behavior Analysis | Correlate and analyze the behavior of multiple systems. | Sensor Fusion and Analysis | AU-6(3), AU-6(5) |
| CM2019 | Endpoint Scrutiny | Scrutinize the contents and behavior patterns of an endpoint system. | Forensic and Behavioral Analysis | IR-4(12) |
| CM2020 | Application- or Utility-Specific Monitoring | Monitor and analyze events in the context of a specific application or utility. | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(2) |
| CM2021 | Account Monitoring | Monitor and analyze activity associated with user accounts for indications of unusual or suspicious use. | Monitoring and Damage Assessment, Behavior Validation | AC-2(12), IR-4(13), SI-4(2) |
| CM2022 | Host-Local Event Correlation | Correlate and analyze events occurring on a single host. | Sensor Fusion and Analysis, Monitoring and Damage Assessment | IR-4(13), SI-4(16) |
| CM2023 | Centralize and Analyze Instance Logging | Centralize instance logging in a cloud or container environment and analyze. | Sensor Fusion and Analysis | AU-6(5), IR-4(4) |
| CM2029 | Monitor Script Execution | Monitor for the execution of scripts that are unknown or used in suspicious ways. | Monitoring and Damage Assessment | IR-4(13), SI-4(2), SI-4(13) |
| CM2030 | Monitor and Analyze API Use | Monitor and analyze uses of application interfaces (APIs). | Monitoring and Damage Assessment | IR-4(13), SI-4(2), SI-4(13) |
| CM2033 | Monitor the File System | Monitor the file system to identify the unexpected presence and atypical use of files of specific types or atypical patterns of access. | Monitoring and Damage Assessment, Sensor Fusion and Analysis, Behavior Validation | IR-4(13), SI-4(2), SI-4(24) |
| CM2034 | Monitor Specific Servers | Monitor specific servers for anomalous or suspicious uses or access attempts. | Monitoring and Damage Assessment | IR-4(13), SI-4(2) |
| CM2035 | Monitor Specific Files | Monitor the use of specific files or directories for anomalous or suspicious uses or access attempts. | Behavior Validation, Monitoring and Damage Assessment | AU-6 |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|--|--|--|--------------------------------------|
| CM2038 | Monitor Command Line Use | Monitor use of the command line interface for common utilities (part of the system or installed by the adversary) and suspicious behavior. | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(2), SI-4(4), SI-4(13) |
| CM2040 | Monitor Use of Libraries and Utilities | Monitor the use of libraries and utilities that are commonly used to support adversary actions. | Monitoring and Damage Assessment | IR-4(13), SI-4(2), SI-4(4), SI-4(13) |
| CM2041 | Analyze Network Traffic Content | Analyze the contents of network traffic. | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(13), SI-4(25) |
| CM2042 | Analyze Outgoing Traffic Patterns | Analyze outgoing traffic for patterns of behavior that could indicate adversary communications. | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(18) |
| CM2043 | Monitor External Sources | Monitor and analyze external information sources for indicators of adversary activities, especially those targeting the organization. | Monitoring and Damage Assessment, Dynamic Threat Awareness | PM-16, RA-10 |
| CM2044 | Monitor Platform Status | Monitor the status of platforms (e.g., user endpoints, servers, network devices). | Monitoring and Damage Assessment | IR-4(13), SI-4(2) |
| CM2047 | Monitor Network Usage | Monitor network usage for anomalous behavior. | Monitoring and Damage Assessment, Behavior Validation | IR-4(13), SI-4(11), SI-4(13) |
| CM2048 | Hunt for Malicious Processes | Hunt for applications or processes that display specific malicious or suspect behaviors. | Forensic and Behavioral Analysis | IR-5 |

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TABLE F-19: CANDIDATE MITIGATIONS TO INCREASE THE EFFECTIVENESS OF OTHER MITIGATIONS

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|--|---|---|---|
| CM1301 | Dynamic Threat Awareness and Response | Use awareness of the current threat landscape to inform threat hunting and threat-adaptive defenses. | Adaptive Management, Sensor Fusion and Analysis, Dynamic Threat Awareness | RA-3(3), RA-5(10), RA-10, PM-16, PM-16(1) |
| CM1302 | Mission-Oriented Cyber Situational Awareness | Maintain awareness of mission dependencies and the current status of mission-critical assets to inform threat-adaptive responses. | Sensor Fusion and Analysis, Mission Dependency and Status Visualization | SI-4(1), SI-4(2) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|--|--|---|---|
| CM1303 | Integrated Non-Disruptive Response | Integrate automated and human-directed response to suspicious events to minimize disruption. | Monitoring and Damage Assessment, Sensor Fusion and Analysis, Adaptive Management | SI-4(3), SI-4(7), SI-7(5) |
| CM1304 | Enhance via Unpredictability | Enhance the effectiveness of defender actions by using capabilities unpredictably or by adding noise or false information to query responses. | Contextual Unpredictability, Temporal Unpredictability | SC-30(2), SI-19(6) |
| CM1305 | Enhance via Heterogeneity | Increase barriers to adversary effectiveness by providing architecturally diverse system components. | Architectural Diversity | AU-9(7), SC-29, SC-29(1) |
| CM1306 | Lock Down Usage | Restrict access to applications and configurations as part of the installation process, and narrowly restrict modifications or other uses of privileged functions. | Attribute-Based Usage Restriction, Trust-Based Privilege Management | AC-3(12), AC-6(10), CM-5(5), CM-5(6), CM-7(4) |
| CM1307 | Enhance via Layered Protections | Provide similar capabilities or mechanisms at multiple architectural layers. | Calibrated Defense-in-Depth | PL-8(1), SC-3(5) |
| CM1308 | Separate Environments with Specific Risks | Provide environments separate from the operational environment for activities with specific risks. | Monitoring and Damage Assessment, Predefined Segmentation | AU-6(8), CM-4(1), SC-7(13) |
| CM1309 | Vulnerability-Oriented Cyber Situational Awareness | Maintain awareness of the vulnerability posture over time to inform the calibration of detection and proactive responses. | Sensor Fusion and Analysis | RA-5(6), RA-5(8), RA-5(10) |
| CM1310 | Protect Distributed Processing and Storage | Provide supporting protections for distributed processing and distributed or replicated storage. | Behavior Validation, Replication | SC-36(1), SC-36(2) |
| CM1311 | Enhance via Isolation | Enhance the effectiveness of or confidence in security functions via system mechanisms for isolation. | Predefined Segmentation, Dynamic Segmentation and Isolation | SC-3(2), SC-39(2), SC-50 |
| CM1312 | Enhance Isolation via Hardware Features | Enhance the effectiveness of or confidence in isolation by using underlying hardware features. | Predefined Segmentation, Dynamic Segmentation and Isolation | SC-3(1), SC-39(1), SC-49 |
| CM1313 | Validate or Assess Control Effectiveness in Practice | Validate or assess the effectiveness of controls as implemented and used in practice. | Self-Challenge, Protected Backup and Restore, Integrity Checks | CP-4(5), CP-9(1), SI-19(8) |

| Identifier | Name | Description | Cyber Resiliency Approaches | Controls |
|---------------|-----------------------------|---|--|--|
| CM1314 | Enhance via Automation | Use automation to increase the effectiveness or quality of capabilities or practices. | Adaptive Management, Monitoring and Damage Assessment, Sensor Fusion and Analysis, Dynamic Threat Awareness, Integrity Checks, Behavior Validation | CA-7(6) , PE-6(2), PM-16(1), RA-5(6), SI-4(2), SI-4(3), SI-4(7), SI-7(5) |
| CM1315 | Maintain a War-Time Reserve | Maintain a reserve of critical components, both special-purpose and acquired, for use in a crisis situation. | Mission Dependency and Status Visualization, Specialization, Replication | RA-9, SA-20, SA-23, SR-5(1) |
| CM1316 | Enhance via Coordination | Coordinate across the organization and with external stakeholders to increase the effectiveness or timeliness of responsive capabilities and practices. | Adaptive Management, Orchestration | CP-2(1), IR-4(10), IR-4(11) |

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