

NIST SPECIAL PUBLICATION 1800-10

Protecting Information and System Integrity in Industrial Control System Environments: Cybersecurity for the Manufacturing Sector

Includes Executive Summary (A); Approach, Architecture, and Security Characteristics (B); and How-To Guides (C)

Michael Powell

National Cybersecurity Center of Excellence
National Institute of Standards and Technology

Joseph Brule*

Cyber Security Directorate
National Security Agency

Michael Pease

Keith Stouffer

CheeYee Tang

Timothy Zimmerman

Engineering Laboratory
National Institute of Standards and Technology

Chelsea Deane

John Hoyt

Mary Raguso

Aslam Sherule

Kangmin Zheng

The MITRE Corporation
McLean, Virginia

Matthew Zopf

Stratavia
Largo, Maryland

*Former employee; all work for this publication done while at employer.

September 2021

DRAFT

This publication is available free of charge from

<https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics>

NIST SPECIAL PUBLICATION 1800-10

**Protecting Information and System Integrity in Industrial Control
System Environments:
Cybersecurity for the Manufacturing Sector**

*Includes Executive Summary (A); Approach, Architecture, and Security Characteristics (B);
and How-To Guides (C)*

Michael Powell
*National Cybersecurity Center of Excellence
National Institute of Standards and Technology*

Joseph Brule
*Cyber Security Directorate
National Security Agency*

Michael Pease
Keith Stouffer
CheeYee Tang
Timothy Zimmerman
*Engineering Laboratory
National Institute of Standards and Technology*

Chelsea Deane
John Hoyt
Mary Raguso
Aslam Sherule
Kangmin Zheng
*The MITRE Corporation
McLean, Virginia*

Matthew Zopf
*Stratavia
Largo, Maryland*

DRAFT

September 2021



U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
*James K. Olthoff, Performing the Non-Exclusive Functions and Duties of the Under Secretary of Commerce
for Standards and Technology & Director, National Institute of Standards and Technology*

DRAFT

NIST SPECIAL PUBLICATION 1800-10A

Protecting Information and System Integrity in Industrial Control System Environments: Cybersecurity for the Manufacturing Sector

Volume A: Executive Summary

Michael Powell

National Cybersecurity Center of Excellence
National Institute of Standards and Technology

Joseph Brule*

Cyber Security Directorate
National Security Agency

Michael Pease

Keith Stouffer

CheeYee Tang

Timothy Zimmerman

Engineering Laboratory
National Institute of Standards and Technology

Chelsea Deane

John Hoyt

Mary Raguso

Aslam Sherule

Kangmin Zheng

The MITRE Corporation
McLean, Virginia

Matthew Zopf

Stratavia

Largo, Maryland

*Former employee; all work for this publication done while at employer.

September 2021

DRAFT

This publication is available free of charge from
<https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics>

1 Executive Summary

2 Many manufacturing organizations rely on industrial control systems (ICS) to monitor and control their
3 machinery, production lines, and other physical processes that produce goods. To stay competitive,
4 manufacturing organizations are increasingly connecting their operational technology (OT) systems to
5 their information technology (IT) systems to enable and expand enterprise-wide connectivity and
6 remote access for enhanced business processes and capabilities.

7 Although the integration of IT and OT networks is helping manufacturers boost productivity and gain
8 efficiencies, it has also provided malicious actors, including nation states, common criminals, and insider
9 threats, a fertile landscape where they can exploit cybersecurity vulnerabilities to compromise the
10 integrity of ICS and ICS data to reach their end goal. The motivations behind these attacks can range
11 from degrading manufacturing capabilities to financial gain, to causing reputational harm.

12 Once malicious actors gain access, they can harm an organization by compromising data or system
13 integrity, hold ICS and/or OT systems ransom, damage ICS machinery, or cause physical injury to
14 workers. The statistics bear this out. The [X-Force Threat Intelligence Index 2021 \(ibm.com\)](#) stated that
15 manufacturing was the second-most-attacked industry in 2020, up from eighth place in 2019.

16 One particular case study illustrates the long-lasting effects and damage a single cyber attack can inflict
17 on an organization. It was reported that a global pharmaceutical manufacturer suffered a cyber attack
18 that caused temporary production delays at a facility making a key vaccination. More than 30,000 laptop
19 and desktop computers, along with 7,500 servers, sat idle. Although the company claimed that its
20 operations were back to normal within six months of the incident, at this writing, news reports stated
21 that the organization is locked in a legal battle with its insurers and is looking to reclaim expenses that
22 include repairing its computer networks and the costs associated with interruptions to its operations.
23 They are seeking more than \$1.3 billion in damages.

24 To address the cybersecurity challenges facing the manufacturing sector, the National Institute of
25 Standards and Technology's (NIST's) National Cybersecurity Center of Excellence (NCCoE) launched this
26 project in partnership with NIST's Engineering Laboratory (EL) and cybersecurity technology providers.
27 Together, we have built example solutions that manufacturing organizations can use to mitigate ICS
28 integrity risks, strengthen the cybersecurity of OT systems, and protect the data that these systems
29 process.

30 CHALLENGE

31 The manufacturing industry is critical to the economic well-being of our nation, and is constantly seeking
32 ways to modernize its systems, boost productivity, and raise efficiency. To meet these goals,
33 manufacturers are modernizing their OT systems by making them more interconnected and integrated
34 with other IT systems and introducing automated methods to strengthen their overall OT asset
35 management capabilities.

36 As OT and IT systems become increasingly interconnected, manufacturers have become a major target
37 of more widespread and sophisticated cybersecurity attacks, which can disrupt these processes and

38 cause damage to equipment and/or injuries to workers. Furthermore, these incidents could significantly
 39 impact productivity and raise operating costs, depending on the extent of a cyber attack.

This practice guide can help your organization:

- detect and prevent unauthorized software installation
- protect ICS networks from potentially harmful applications
- determine changes made to a network using change management tools
- detect unauthorized use of systems
- continuously monitor network traffic
- leverage malware tools

40 **SOLUTION**

41 The NCCoE, in conjunction with the NIST EL, collaborated with cybersecurity technology providers to
 42 develop and implement example solutions that demonstrate how manufacturing organizations can
 43 protect the integrity of their data from destructive malware, insider threats, and unauthorized software
 44 within manufacturing environments that rely on ICS.

45 The example solutions use technologies and security capabilities from the project collaborators listed in
 46 the table below. These technologies were implemented in two distinct manufacturing lab environments
 47 that emulate discrete and continuous manufacturing systems. This project takes a modular approach in
 48 demonstrating two unique builds in each of the lab environments.

49 The following is a list of the project’s collaborators.

Collaborator	Component
 DISPEL	Provides secure remote access with authentication and authorization support.
 DRAGOS	Provides network and asset monitoring to detect behavior anomalies and modifications to hardware, firmware, and software capabilities.
 FORESCOUT	Provides network and asset monitoring to detect behavior anomalies and modifications to hardware, firmware, and software capabilities.
 GreenTec™ www.GreenTec-USA.com	Offers secure data storage on-prem.
 Microsoft	Provides network and asset monitoring to detect behavior anomalies and modifications to hardware, firmware, and software capabilities.
 OSIsoft. is now part of AVEVA	Real-time data management software that enables detection of behavior anomalies and modifications to hardware, firmware, and software capabilities.

Collaborator	Component
	Access control platform that secures connections and provides control mechanisms to enterprise systems for authorized users and devices; monitors activity down to the keystroke
	Provides network and asset monitoring to detect behavior anomalies and modifications to hardware, firmware, and software capabilities.
	Provides host-based application allowlisting (the blocking of unauthorized activities that have the potential to pose a harmful attack) and file integrity monitoring.

50 While the NCCoE used a suite of commercial products to address this challenge, this guide does not
 51 endorse these particular products, nor does it guarantee compliance with any regulatory initiatives. Your
 52 organization's information security experts should identify the products that will best integrate with
 53 your existing tools and IT system infrastructure. Your organization can adopt this solution or one that
 54 adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and
 55 implementing parts of a solution.

56 HOW TO USE THIS GUIDE

57 Depending on your role in your organization, you might use this guide in different ways:

58 **Business decision makers, including chief information security and technology officers,** can use this
 59 part of the guide, *NIST SP 1800-10A: Executive Summary*, to understand the drivers for the guide, the
 60 cybersecurity challenge we address, our approach to solving this challenge, and how the solution could
 61 benefit your organization.

62 **Technology, security, and privacy program managers** who are concerned with how to identify,
 63 understand, assess, and mitigate risk can use *NIST SP 1800-10B: Approach, Architecture, and Security*
 64 *Characteristics*. It describes what we built and why, including the risk analysis performed and the
 65 security/privacy control mappings.

66 **IT professionals** who want to implement an approach like this can make use of *NIST SP 1800-10C: How-*
 67 *To Guides*. It provides specific product installation, configuration, and integration instructions for
 68 building the example implementation, allowing you to replicate all or parts of this project.

69 SHARE YOUR FEEDBACK

70 You can view or download the preliminary draft guide at [https://www.nccoe.nist.gov/projects/use-](https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics)
 71 [cases/manufacturing/integrity-ics](https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics). Help the NCCoE make this guide better by sharing your thoughts with
 72 us. There will be at least 45 additional days for the comment period for this guide.

73 Once the example implementation is developed, you can adopt this solution for your own organization.
 74 If you do, please share your experience and advice with us. We recognize that technical solutions alone
 75 will not fully enable the benefits of our solution, so we encourage organizations to share lessons learned
 76 and best practices for transforming the processes associated with implementing this guide.

77 To provide comments, join the community of interest, or to learn more about the project and example
78 implementation, contact the NCCoE at manufacturing_nccoe@nist.gov.

79 **COLLABORATORS**

80 Collaborators participating in this project submitted their capabilities in response to an open call in the
81 Federal Register for all sources of relevant security capabilities from academia and industry (vendors
82 and integrators). Those respondents with relevant capabilities or product components signed a
83 Cooperative Research and Development Agreement (CRADA) to collaborate with NIST in a consortium to
84 build this example solution.

85 Certain commercial entities, equipment, products, or materials may be identified by name or company
86 logo or other insignia in order to acknowledge their participation in this collaboration or to describe an
87 experimental procedure or concept adequately. Such identification is not intended to imply special
88 status or relationship with NIST or recommendation or endorsement by NIST or NCCoE; neither is it
89 intended to imply that the entities, equipment, products, or materials are necessarily the best available
90 for the purpose.

DRAFT

NIST SPECIAL PUBLICATION 1800-10B

Protecting Information and System Integrity in Industrial Control System Environments: Cybersecurity for the Manufacturing Sector

Volume B:
Approach, Architecture, and Security Characteristics

Michael Powell

National Cybersecurity Center of Excellence
National Institute of Standards and Technology

Joseph Brule*

Cyber Security Directorate
National Security Agency

Michael Pease

Keith Stouffer

CheeYee Tang

Timothy Zimmerman

Engineering Laboratory
National Institute of Standards and Technology

Chelsea Deane

John Hoyt

Mary Raguso

Aslam Sherule

Kangmin Zheng

The MITRE Corporation
McLean, Virginia

Matthew Zopf

Strativia
Largo, Maryland

*Former employee; all work for this publication done while at employer.

September 2021

DRAFT

This publication is available free of charge from
<https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics>



1 **DISCLAIMER**

2 Certain commercial entities, equipment, products, or materials may be identified by name or company
3 logo or other insignia in order to acknowledge their participation in this collaboration or to describe an
4 experimental procedure or concept adequately. Such identification is not intended to imply special
5 status or relationship with NIST or recommendation or endorsement by NIST or NCCoE; neither is it
6 intended to imply that the entities, equipment, products, or materials are necessarily the best available
7 for the purpose.

8 While NIST and NCCoE address goals of improving the management of cybersecurity and privacy risk
9 through outreach and application of standards and best practices, it is the stakeholder’s responsibility to
10 fully perform a risk assessment to include the current threat, vulnerabilities, likelihood of a compromise
11 and the impact should the threat be realized before adopting cyber security measures such as this
12 recommendation.

13 Domain name and IP addresses shown in this guide represent an example domain and network
14 environment to demonstrate the NCCoE project use case scenarios and the security capabilities.

15 National Institute of Standards and Technology Special Publication 1800-10B, Natl. Inst. Stand. Technol.
16 Spec. Publ. 1800-10B, 170 pages, (September 2021), CODEN: NSPUE2

17 **FEEDBACK**

18 You can improve this guide by contributing feedback. As you review and adopt this solution for your
19 own organization, we ask you and your colleagues to share your experience and advice with us.

20 Comments on this publication may be submitted to: manufacturing_nccoe@nist.gov.

21 Public comment period: September 23, 2021 through November 07, 2021

22 All comments are subject to release under the Freedom of Information Act (FOIA).

23 National Cybersecurity Center of Excellence
24 National Institute of Standards and Technology
25 100 Bureau Drive
26 Mailstop 2002
27 Gaithersburg, MD 20899
28 Email: nccoe@nist.gov

29 NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

30 The National Cybersecurity Center of Excellence (NCCoE), a part of the National Institute of Standards
31 and Technology (NIST), is a collaborative hub where industry organizations, government agencies, and
32 academic institutions work together to address businesses' most pressing cybersecurity issues. This
33 public-private partnership enables the creation of practical cybersecurity solutions for specific
34 industries, as well as for broad, cross-sector technology challenges. Through consortia under
35 Cooperative Research and Development Agreements (CRADAs), including technology partners—from
36 Fortune 50 market leaders to smaller companies specializing in information technology security—the
37 NCCoE applies standards and best practices to develop modular, easily adaptable example cybersecurity
38 solutions using commercially available technology. The NCCoE documents these example solutions in
39 the NIST Special Publication 1800 series, which maps capabilities to the NIST *Cybersecurity Framework*
40 and details the steps needed for another entity to re-create the example solution. The NCCoE was
41 established in 2012 by NIST in partnership with the State of Maryland and Montgomery County,
42 Maryland.

43 To learn more about the NCCoE, visit <https://www.nccoe.nist.gov/>. To learn more about NIST, visit
44 <https://www.nist.gov>.

45 NIST CYBERSECURITY PRACTICE GUIDES

46 NIST Cybersecurity Practice Guides (Special Publication 1800 series) target specific cybersecurity
47 challenges in the public and private sectors. They are practical, user-friendly guides that facilitate the
48 adoption of standards-based approaches to cybersecurity. They show members of the information
49 security community how to implement example solutions that help them align more easily with relevant
50 standards and best practices, and provide users with the materials lists, configuration files, and other
51 information they need to implement a similar approach.

52 The documents in this series describe example implementations of cybersecurity practices that
53 businesses and other organizations may voluntarily adopt. These documents do not describe regulations
54 or mandatory practices, nor do they carry statutory authority.

55 ABSTRACT

56 Today's manufacturing organizations rely on industrial control systems (ICS) to conduct their operations.
57 Increasingly, ICS are facing more frequent, sophisticated cyber attacks—making manufacturing the
58 second-most-targeted industry [1]. Cyber attacks against ICS threaten operations and worker safety,
59 resulting in financial loss and harm to the organization's reputation.

60 The architecture and solutions presented in this guide are built upon standards-based, commercially
61 available products, and represent some of the possible solutions. The solutions implement standard
62 cybersecurity capabilities such as behavioral anomaly detection (BAD), application allowlisting, file
63 integrity-checking, change control management, and user authentication and authorization. The
64 solution was tested in two distinct lab settings: a discrete manufacturing workcell, which represents an
65 assembly line production, and a continuous process control system, which represents chemical
66 manufacturing industries.

67 An organization that is interested in protecting the integrity of a manufacturing system and information
 68 from destructive malware, insider threats, and unauthorized software should first conduct a risk
 69 assessment and determine the appropriate security capabilities required to mitigate those risks. Once
 70 the security capabilities are identified, the sample architecture and solution presented in this document
 71 may be used.

72 The security capabilities of the example solution are mapped to the [NIST Cybersecurity Framework](#), the
 73 [National Initiative for Cybersecurity Education Framework](#), and [NIST Special Publication 800-53](#).

74 KEYWORDS

75 *Manufacturing; industrial control systems; application allowlisting; file integrity checking; user*
 76 *authentication; user authorization; behavioral anomaly detection; remote access; software modification;*
 77 *firmware modification.*

78 ACKNOWLEDGEMENTS

79 We are grateful to the following individuals for their generous contributions of expertise and time.

Name	Organization
Dan Frechette	Microsoft
Ian Schmertzler	Dispel
Ben Burke	Dispel
Chris Jensen	Tenable
Bethany Brower	VMWare
Dennis Hui	OSIssoft (now part of AVEVA)
John Matranga	OSIssoft (now part of AVEVA)
Michael A. Piccalo	Forescout
Tim Jones	Forescout
Yejin Jang	Forescout
Samantha Pelletier	TDI Technologies
Rusty Hale	TDI Technologies
Steve Petruzzo	GreenTec
Josh Carlson	Dragos
Alex Baretta	Dragos

80 The Technology Partners/Collaborators who participated in this build submitted their capabilities in
 81 response to a notice in the Federal Register. Respondents with relevant capabilities or product
 82 components were invited to sign a Cooperative Research and Development Agreement (CRADA) with
 83 NIST, allowing them to participate in a consortium to build this example solution. We worked with:

Technology Partner/Collaborator	Product
Carbon Black (VMware)	Carbon Black App Control
Microsoft	Azure Defender for the internet of things (IoT) (incorporating technology from the acquisition of CyberX)
Dispel	Dispel Wicket ESI Dispel Enclave Dispel VDI (Virtual Desktop Interface)
Dragos	Dragos Platform
Forescout	eyeInspect (Formerly SilentDefense) ICS Patrol EyeSight
GreenTec	WORMdisk and ForceField
OSIsoft (now part of AVEVA)	PI System (which comprises products such as PI Server, PI Vision and others)
TDi Technologies	ConsoleWorks
Tenable	Tenable.ot

84 DOCUMENT CONVENTIONS

85 The terms “shall” and “shall not” indicate requirements to be followed strictly to conform to the
86 publication and from which no deviation is permitted. The terms “should” and “should not” indicate that
87 among several possibilities, one is recommended as particularly suitable without mentioning or
88 excluding others, or that a certain course of action is preferred but not necessarily required, or that (in
89 the negative form) a certain possibility or course of action is discouraged but not prohibited. The terms
90 “may” and “need not” indicate a course of action permissible within the limits of the publication. The
91 terms “can” and “cannot” indicate a possibility and capability, whether material, physical, or causal.

92 CALL FOR PATENT CLAIMS

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

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

101 a) assurance in the form of a general disclaimer to the effect that such party does not hold and does not
102 currently intend holding any essential patent claim(s); or

103 b) assurance that a license to such essential patent claim(s) will be made available to applicants desiring
104 to utilize the license for the purpose of complying with the guidance or requirements in this ITL draft
105 publication either:

- 106 1. under reasonable terms and conditions that are demonstrably free of any unfair discrimination;
107 or
- 108 2. without compensation and under reasonable terms and conditions that are demonstrably free
109 of any unfair discrimination

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

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

117 Such statements should be addressed to: manufacturing_nccoe@nist.gov

118	Contents	
119	1 Summary	1
120	1.1 Challenge	2
121	1.2 Solution	3
122	1.2.1 Relevant Standards and Guidance	3
123	1.3 Benefits	4
124	2 How to Use This Guide	4
125	2.1 Typographic Conventions	6
126	3 Approach	6
127	3.1 Audience	6
128	3.2 Scope	7
129	3.3 Assumptions	7
130	3.4 Risk Assessment	8
131	3.4.1 Threats	8
132	3.4.2 Vulnerabilities	9
133	3.4.3 Risk	10
134	3.4.4 Security Control Map	10
135	3.5 Technologies	13
136	4 Architecture	14
137	4.1 Manufacturing Process and Control System Description	15
138	4.2 Cybersecurity for Smart Manufacturing Systems Architecture	15
139	4.3 Process Control System	16
140	4.4 Collaborative Robotics System (CRS)	19
141	4.5 Logical Network and Security Architectures	21
142	4.5.1 Build 1	21
143	4.5.2 Build 2	25
144	4.5.3 Build 3	28
145	4.5.4 Build 4	30
146	5 Security Characteristic Analysis	32
147	5.1 Assumptions and Limitations	32
148	5.2 Example Solution Testing	32
149	5.2.1 Scenario 1: Protect Host from Malware Infection via USB	33

150 5.2.2 Scenario 2: Protect Host from Malware Infection via Network Vector34

151 5.2.3 Scenario 3: Protect Host from Malware via Remote Access Connections35

152 5.2.4 Scenario 4: Protect Host from Unauthorized Application Installation36

153 5.2.5 Scenario 5: Protect from Unauthorized Addition of a Device38

154 5.2.6 Scenario 6: Detect Unauthorized Device-to-Device Communications39

155 5.2.7 Scenario 7: Protect from Unauthorized Deletion of Files.....40

156 5.2.8 Scenario 8: Detect Unauthorized Modification of PLC Logic41

157 5.2.9 Scenario 9: Protect from Modification of Historian Data42

158 5.2.10 Scenario 10: Detect Sensor Data Manipulation.....44

159 5.2.11 Scenario 11: Detect Unauthorized Firmware Modification.....44

160 5.3 Scenarios and Findings 46

161 5.3.1 PR.AC-1: Identities and credentials are issued, managed, verified, revoked, and

162 audited for authorized devices, users, and processes.....46

163 5.3.2 PR.AC-3: Remote access is managed46

164 5.3.3 PR.AC-4: Access permissions and authorizations are managed, incorporating the

165 principles of least privilege and separation of duties.....46

166 5.3.4 PR.AC-7: Users, devices, and other assets are authenticated (e.g., single-factor, multi-

167 factor) commensurate with the risk of the transaction (e.g., individuals’ security and

168 privacy risks and other organizational risks).....47

169 5.3.5 PR.DS-1: Data-at-rest is protected.....47

170 5.3.6 PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and

171 information integrity.....47

172 5.3.7 PR.IP-4: Backups of information are conducted, maintained, and tested47

173 5.3.8 PR.MA-1: Maintenance and repair of organizational assets are performed and logged,

174 with approved and controlled tools47

175 5.3.9 PR.MA-2: Remote maintenance of organizational assets is approved, logged, and

176 performed in a manner that prevents unauthorized access48

177 5.3.10 DE.AE-1: A baseline of network operations and expected data flows for users and

178 systems is established and managed.....48

179 5.3.11 DE.AE-2: Detected events are analyzed to understand attack targets and methods 48

180 5.3.12 DE.AE-3: Event data are collected and correlated from multiple sources and sensors .

18148

182 5.3.13 DE.CM-1: The network is monitored to detect potential cybersecurity events.....49

183 5.3.14 DE.CM-3: Personnel activity is monitored to detect potential cybersecurity events 49

184 5.3.15 DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software

185 is performed.....49

186 **6 Future Build Considerations 50**

187 **Appendix A List of Acronyms 51**

188 **Appendix B Glossary 53**

189 **Appendix C References 57**

190 **Appendix D Scenario Execution Results 59**

191 D.1 Executing Scenario 1: Protect Host from Malware via USB 59

192 D.1.1 Build 1 59

193 D.1.2 Build 2 61

194 D.1.3 Build 3 61

195 D.1.4 Build 4 62

196 D.2 Executing Scenario 2: Protect Host from Malware via Network Vector 63

197 D.2.1 Build 1 64

198 D.2.2 Build 2 67

199 D.2.3 Build 3 73

200 D.2.4 Build 4 77

201 D.3 Executing Scenario 3: Protect Host from Malware via Remote Access

202 Connections 81

203 D.3.1 Build 1 81

204 D.3.2 Build 2 83

205 D.3.3 Build 3 85

206 D.3.4 Build 4 87

207 D.4 Executing Scenario 4: Protect Host from Unauthorized Application Installation 89

208 D.4.1 Build 1 89

209 D.4.2 Build 2 91

210 D.4.3 Build 3 93

211 D.4.4 Build 4 96

212 D.5 Executing Scenario 5: Protect from Unauthorized Addition of a Device 99

213 D.5.1 Build 1 100

214 D.5.2 Build 2 101

215 D.5.3 Build 3 102

216 D.5.4 Build 4 106

217 D.6 Executing Scenario 6: Detect Unauthorized Device-to-Device Communications 108

218 D.6.1 Build 1 108

219	D.6.2	Build 2	109
220	D.6.3	Build 3	110
221	D.6.4	Build 4	111
222	D.7	Executing Scenario 7: Protect from Unauthorized Deletion of Files	112
223	D.7.1	Build 1	112
224	D.7.2	Build 2	113
225	D.7.3	Build 3	114
226	D.7.4	Build 4	115
227	D.8	Executing Scenario 8: Detect Unauthorized Modification of PLC Logic.....	116
228	D.8.1	Build 1	116
229	D.8.2	Build 2	119
230	D.8.3	Build 3	123
231	D.8.4	Build 4	126
232	D.9	Executing Scenario 9: Protect from Modification of Historian Data.....	128
233	D.9.1	Build 1	128
234	D.9.2	Build 2	130
235	D.9.3	Build 3	132
236	D.9.4	Build 4	134
237	D.10	Executing Scenario 10: Detect Sensor Data Manipulation	136
238	D.10.1	All Builds.....	136
239	D.11	Executing Scenario 11: Detect Unauthorized Firmware Modification	137
240	D.11.1	Build 1	137
241	D.11.2	Build 2	138
242	D.11.3	Build 3	141
243	D.11.4	Build 4	142
244	Appendix E Benefits of IoT Cybersecurity Capabilities		144
245	E.1	Device Capabilities Mapping	144
246	E.2	Device Capabilities Supporting Functional Test Scenarios.....	155

247 **List of Figures**

248 **Figure 4-1: CSMS Network Architecture16**

249 **Figure 4-2: Simplified Tennessee Eastman Process Model17**

250 **Figure 4-3: HMI Screenshot for the PCS Showing the Main Components in the Process18**

251 **Figure 4-4: PCS Network.....19**

252 **Figure 4-5: The CRS Workcell20**

253 **Figure 4-6: CRS Network.....21**

254 **Figure 4-7: Build 1, PCS Complete Architecture with Security Components24**

255 **Figure 4-8: Build 2, PCS Complete Architecture with Security Components27**

256 **Figure 4-9: Build 3, CRS Complete Architecture with Security Components29**

257 **Figure 4-10: Build 4, CRS Complete Architecture with Security Components31**

258 **Figure D-1: An Alert from Carbon Black Showing that Malware (1.exe) was Blocked from Executing ..60**

259 **Figure D-2: Carbon Black’s Server Provides Additional Details and Logs of the Event60**

260 **Figure D-3: Carbon Black’s Server Log of the Event.....61**

261 **Figure D-4: Windows 7 Alert as a Result of Windows SRP Blocking the Execution of 1.exe.....61**

262 **Figure D-5: Windows 10 Alert as a Result of Windows SRP Blocking the Execution of 1.exe.....62**

263 **Figure D-6: Carbon Black Blocks the Execution of 1.exe for Build 4.....63**

264 **Figure D-7: Tenable.ot Dashboard Showing the Events that were Detected64**

265 **Figure D-8: Detected RDP Session Activity from External System to DMZ System65**

266 **Figure D-9: Event Detection Detail for the RDP Connection from the External System to the**

267 **Historian in the DMZ.....65**

268 **Figure D-10: Tenable.ot Detected VNC Connection Between the DMZ and the Testbed LAN.....65**

269 **Figure D-11: Tenable.ot Event Detail for a Detected Port Scan from a DMZ System Targeting a**

270 **System in the Testbed LAN.....66**

271 **Figure D-12: Detected RDP from a DMZ system to a Testbed LAN system66**

272 **Figure D-13: Tenable.ot Event Detail Showing the RDP Connection Between the Historian in**

273 **the DMZ to a Workstation in the Testbed LAN66**

274 **Figure D-14: Attempt to Execute 1.exe Failed.....67**

275 **Figure D-15: Alert Dashboard Showing Detection of an RDP Session.....68**

276 **Figure D-16: Details of the Detected RDP Session Activity from an External System to DMZ System ...69**

277 Figure D-17: Detection of Scanning Traffic and RDP Connection into Manufacturing Environment.....70

278 Figure D-18: Details of One of the Port Scan Alerts.....71

279 Figure D-19: Details of Alert for RDP Connection into Manufacturing Environment72

280 Figure D-20: Dialog Message Showing 1.exe was Blocked from Executing73

281 Figure D-21: Windows SRP blocked 1.exe From Executing74

282 Figure D-22: Log of Alerts Detected by Dragos.....74

283 Figure D-23: Detail of RDP Session Activity Between an External System and a DMZ System75

284 Figure D-24: Detail for Network Scanning Alert76

285 Figure D-25: Detail of RDP Session Activity Between a DMZ System and a Testbed LAN System76

286 Figure D-26: Azure Defender for IoT “info” Event Identified the Remote Access Connection to

287 the DMZ77

288 Figure D-27: Alert for Scanning Activity.....78

289 Figure D-28: Details for the Scanning Alert.....79

290 Figure D-29: Detection of RDP Connection into the Manufacturing Environment80

291 Figure D-30: Carbon Black Shows an Alert for Blocking File 1.exe.....81

292 Figure D-31: Secured VPN Connection to Environment with Cisco AnyConnect82

293 Figure D-32: Remote Access is Being Established Through ConsoleWorks83

294 Figure D-33: Dispel VDI with Interface for Connecting Through Dispel Enclave to Dispel Wicket ESI....84

295 Figure D-34: Nested RDP Session Showing Dispel Connection into the PCS Workstation.....85

296 Figure D-35: VPN Connection to Manufacturing Environment.....86

297 Figure D-36: Remote Access is Being Established Through ConsoleWorks87

298 Figure D-37: Dispel VDI Showing Interface for Connecting Through Dispel Enclave to Dispel Wicket ...88

299 Figure D-38: Nested RDP Session Showing Dispel Connection into the CRS Workstation.....88

300 Figure D-39: Carbon Black Blocks the Execution of putty.exe and Other Files90

301 Figure D-40: Tenable.ot alert Showing the SMB Connection Between the HMI and the GreenTec

302 Server.....91

303 Figure D-41: Tenable.ot Alert Details of the SMB Connection Between the HMI and the network file

304 system (NFS) Server in the DMZ91

305 Figure D-42: Putty.exe is Not Permitted to Run Based on the Windows SRP Configuration92

306 Figure D-43: putty-64bit-0.74-installer.msi is blocked by Windows SRP92

307 Figure D-44: Forescout Alert on the File Transfer Activity93

308 Figure D-45: Forescout Alert Details for the File Transfer Activity93

309 Figure D-46: Putty.exe is Not Permitted to Run Based on the Windows SRP Configuration94

310 Figure D-47: putty-64bit-0.74-installer.msi is Blocked by Windows SRP94

311 Figure D-48: Dragos Alert on the File Transfer Activity.....95

312 Figure D-49: Dragos Alert Details of the File Transfer Alert96

313 Figure D-50: Carbon Black Alert Showing that putty.exe is Blocked from Executing.....97

314 Figure D-51: Carbon Black Alert Showing the Execution of putty-64bit-0.74-installer.msi Being

315 Blocked98

316 Figure D-52: Azure Defender for IoT Alert Dashboard Showing Detection of a New Activity98

317 Figure D-53: Azure Defender for IoT Alert Details Showing RPC Connection Between the DMZ and

318 the Testbed LAN99

319 Figure D-54: Azure Defender for IoT Event Alert Timeline Showing the File Transfer99

320 Figure D-55: Tenable.ot Event Showing a New Asset has Been Discovered..... 101

321 Figure D-56: Tenable.ot Event Showing Unauthorized SSH Activities 101

322 Figure D-57: Forescout Alert on the DNS Request from the New Device..... 102

323 Figure D-58: Forescout alert showing the SSH connection 102

324 Figure D-59: Detailed Forescout alert of the Unauthorized SSH Connection 102

325 Figure D-60: Dragos Dashboard Showing Alerts Generated upon Detecting New Device and Network

326 Scanning..... 104

327 Figure D-61: Details of Network Scanning Activity..... 104

328 Figure D-62: Additional Details of Network Scanning Activity 105

329 Figure D-63: Alert for New Asset on the Network..... 105

330 Figure D-64: Azure Defender for IoT Dashboard Showing the Alerts, Including for the New Asset..... 106

331 Figure D-65: Azure Defender for IoT Detects New Asset in the Environment 107

332 Figure D-66: Azure Defender for IoT Alert Management Options 107

333 Figure D-67: Details for Network Scanning Alert..... 108

334 Figure D-68: Tenable.ot Event Log Showing the Unapproved SSH Traffic..... 109

335 Figure D-69: Forescout Alert Showing the Unapproved SSH Traffic 110

336 Figure D-70: Dragos Alert Showing the Unapproved SSH Connection Between Devices 111

337 Figure D-71: Azure Defender for IoT Event Identified the Unauthorized SSH Connection 112

338 Figure D-72 Event Messages from Carbon Black Showing File Deletion Attempts 113

339 Figure D-73: Security Onion Wazuh Alert Showing a File Has Been Deleted..... 114

340 Figure D-74: Alert from Security Onion for a File Deletion 115

341 **Figure D-75: Carbon Black Alerts Showing That a File Has Been Deleted 116**

342 **Figure D-76: Remote Access to Systems in PCS Network is Being Established Through**

343 **ConsoleWorks..... 117**

344 **Figure D-77: Remote Session into Studio 5000 to Perform PLC File Operations..... 117**

345 **Figure D-78: Tenable.ot Detected the Transfer of PLC Logic File to the Rockwell PLC 118**

346 **Figure D-79: Tenable.ot PLC Stop alert details 118**

347 **Figure D-80: Tenable.ot PLC Program Download Alert Details..... 119**

348 **Figure D-81: Remote Access to Systems in PCS Network is Being Established Through Dispel 120**

349 **Figure D-82: Modifying the Parameters for the Allen-Bradley PLC Controller Using Studio 5000 121**

350 **Figure D-83: Forescout Alerts Showing It Detected the Traffic Between the Engineering Workstation**

351 **and the PLC..... 122**

352 **Figure D-84: Forescout Alert Details for the Stop Command Issued to the PLC 122**

353 **Figure D-85: Forescout Alert Details for the Configuration Download Command..... 123**

354 **Figure D-86: VPN Connection to the Manufacturing Environment..... 124**

355 **Figure D-87: Remote Access is Being Established through ConsoleWorks 124**

356 **Figure D-88: Dragos Notification Manager Showing Detection of the Transfer of PLC Logic File to the**

357 **Beckhoff PLC..... 125**

358 **Figure D-89: Dragos Alert Details for the PLC Logic File Download 126**

359 **Figure D-90: Dispel VDI with Interface for Connecting Through Dispel Enclave to Dispel Wicket 127**

360 **Figure D-91: Nested RDP Connections Showing Dispel Connection into the CRS Workstation 127**

361 **Figure D-92: Azure Defender for IoT Alert for the Unauthorized PLC Programming..... 128**

362 **Figure D-93: Tenable.ot alert Showing SMB Connection from an External Workstation to the**

363 **Historian..... 129**

364 **Figure D-94: GreenTec Denies Modification and Deletion File Operations in the Protected Drive..... 130**

365 **Figure D-95: Forescout Alert Showing Network Connection from the Corporate Network to the**

366 **Historian..... 131**

367 **Figure D-96: GreenTec Denies Modification and Deletion File Operations in the Protected Drive..... 132**

368 **Figure D-97: Dragos Detection of RDP Session from an External Network to the Historian..... 133**

369 **Figure D-98: GreenTec Denies Modification and Deletion File Operations in the Protected Drive..... 134**

370 **Figure D-99: Azure Defender for IoT Event Timeline Showing the Remote Access Connection to the**

371 **Historian..... 135**

372 **Figure D-100: GreenTec Denies Modification and Deletion File Operations in the Protected Drive.... 136**

373 **Figure D-101: PI Server’s Event Frames Showing Out-of-Range Sensor Readings for the Reactor**

374 **Pressure 137**

375 Figure D-102: Tenable.ot Detects a Collection of Events Generated by a Firmware Change138

376 Figure D-103: Details for One of the Alerts Showing the Firmware Change.....138

377 Figure D-104: Forescout Detects a Collection of Alerts Associated with the Firmware Change139

378 Figure D-105: Alert Details Detected by Forescout for the Firmware Change.....140

379 Figure D-106: ICS Patrol Scan Results Showing a Change Configuration was Made141

380 Figure D-107: Dragos Dashboard Showing an Alert for Firmware Change.....142

381 Figure D-108: Details for Firmware Change Alert.....142

382 Figure D-109: Azure Defender for IoT Alert Showing a Version Mismatch in the Firmware Build.....143

383 **List of Tables**

384 Table 3-1: Security Control Map11

385 Table 3-2: Products and Technologies13

386 Table 4-1: Summary of What Products Were Used in Each Build.....15

387 Table 4-2: Build 1 Technology Stack to Capabilities Map.....22

388 Table 4-3: Build 2 Technology Stack to Capabilities Map.....25

389 Table 4-4: Build 3 Technology Stack to Capabilities Map.....28

390 Table 4-5: Build 4 Technology Stack to Capabilities Map.....30

391 Table E-1: Mapping of Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities to

392 *NIST Cybersecurity Framework* Subcategories of the ICS Project.....145

393 Table E-2 Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities that Map to

394 Each of the Functional Test Scenarios155

395 1 Summary

396 While availability is always a critical aspect of manufacturing system environments, manufacturers also
397 need to consider maintaining the integrity of their systems and information to ensure continued
398 operations. The integrity of information can be degraded or lost as a result of behaviors by authorized
399 users (e.g., failure to perform backups or record their actions) or malicious actors seeking to disrupt
400 manufacturing operations for illicit profits, political statements, or other reasons.

401 Manufacturers are unique because of their reliance on industrial control systems (ICS) to monitor and
402 control their manufacturing operations. ICS typically prioritize information availability and integrity over
403 confidentiality. As a result, cybersecurity solutions used in traditional information technology (IT)
404 settings are not optimized to protect ICS from cyber threats.

405 This guide, prepared by the National Cybersecurity Center of Excellence (NCCoE) and the NIST
406 Engineering Laboratory (EL), contains four examples of practical solutions that organizations can
407 implement in their environments to protect ICS from information and system integrity attacks.

408 The goal of this NIST Cybersecurity Practice Guide is to help organizations protect the integrity of
409 systems and information by:

- 410 ▪ securing historical system data
- 411 ▪ preventing execution or installation of unapproved software
- 412 ▪ detecting anomalous behavior on the network
- 413 ▪ identifying hardware, software, or firmware modifications
- 414 ▪ enabling secure remote access
- 415 ▪ authenticating and authorizing users

416 This document provides a detailed description of how each solution was implemented and what
417 technologies were used to achieve each of the above listed goals across four example builds. Scenarios
418 are used to demonstrate the efficacy of the solutions. The results and challenges of each scenario in the
419 four example builds are also presented and discussed.

420 Ultimately, manufacturing organizations that rely on ICS can use the example solutions described in this
421 guide to safeguard their information and system integrity from:

- 422 ▪ destructive malware
- 423 ▪ insider threats
- 424 ▪ unauthorized software
- 425 ▪ unauthorized remote access
- 426 ▪ loss of historical data
- 427 ▪ anomalies network traffic
- 428 ▪ unauthorized modification of systems

429 This document contains the following sections:

430 [Section 1, Summary](#), presents the challenges addressed by the NCCoE project, with a look at the
431 solutions demonstrated to address the challenge, as well as benefits of the solutions.

432 [Section 2, How to Use This Guide](#), explains how readers—business decision makers, program managers,
433 control system engineers, cybersecurity practitioners, and IT professionals (e.g., systems
434 administrators)—might use each volume of this guide.

435 [Section 3, Approach](#), offers a description of the intended audience and the scope of the project. This
436 section also describes the assumptions on which the security architecture and solution development
437 was based, the risk assessment that informed architecture development, the NIST *Cybersecurity*
438 *Framework* functions supported by each component of the architecture and reference design, and
439 which industry collaborators contributed support in building, demonstrating, and documenting the
440 solutions. This section also includes a mapping of the NIST *Cybersecurity Framework* subcategories to
441 other industry guidance, and identifies the products used to address each subcategory.

442 [Section 4, Architecture](#), summarizes the Cybersecurity for Smart Manufacturing Systems (CSMS)
443 demonstration environment, which emulates real-world manufacturing processes and their ICS by using
444 software simulators and commercial off-the-shelf hardware in a laboratory environment. The
445 implementation of the information and system integrity solutions is also described.

446 [Section 5, Security Characteristic Analysis](#), summarizes the scenarios and findings that were employed to
447 demonstrate the example implementations' functionality. Each of the scenarios is mapped to the
448 relevant NIST *Cybersecurity Framework* functions and subcategories and the security capabilities of the
449 products that were implemented. Additionally, it briefly describes how the security capabilities that
450 were used in the solution implementation help detect cyber attacks and protect the integrity of the
451 manufacturing systems and information.

452 [Section 6, Future Build Considerations](#), identifies additional areas that should be reviewed in future
453 practice guides.

454 [Section Appendix D, Scenario Execution Results](#), describes, in detail, the test results of the scenarios,
455 including screenshots from the security products captured during the tests.

456 **1.1 Challenge**

457 Manufacturing organizations that rely on ICS to monitor and control physical processes face risks from
458 malicious and non-malicious insiders along with external threats in the form of increasingly
459 sophisticated cyber attacks. A compromise to system or information integrity may very well pose a
460 significant threat to human safety and can adversely impact an organization's operations, resulting in
461 financial loss and harming production for years to come.

462 Manufacturing organizations may be the targets of malicious cyber actors or may be incidentally
463 impacted by a broader malware event such as ransomware attacks. ICS components remain vulnerable
464 to cyber attacks for numerous reasons, including adoption and integration of enhanced connectivity,
465 remote access, the use of legacy technologies, flat network topologies, lack of network segmentation,

466 and the lack of cybersecurity technologies (e.g., anti-virus, host-based firewalls, encryption) typically
467 found on IT systems.

468 Organizations are increasingly adopting and integrating IT into the ICS environment to enhance
469 connectivity to business systems and to enable remote access. As a result, ICS are no longer isolated
470 from the outside world, making them more vulnerable to cyber attacks. Security controls designed for
471 the IT environment may impact the performance of ICS when implemented within the OT environment,
472 so special precautions are required when introducing these controls. In some cases, new security
473 techniques tailored to the specific ICS environment are needed.

474 Another challenge facing manufacturing organizations comes from authorized users who accidentally or
475 intentionally compromise information and system integrity. For example, a user may install an
476 unapproved software utility to perform maintenance activities or update the logic of a programmable
477 logic controller (PLC) to fix a bug. Even if the software or logic changes are not malicious, they may
478 inadvertently disrupt information flows, starve critical software of processing resources, or degrade the
479 operation of the system. In a worst-case scenario, malware may be inadvertently installed on the
480 manufacturing system, causing disruptions to system operations, or opening a backdoor to remote
481 attackers.

482 1.2 Solution

483 This NCCoE Cybersecurity Practice Guide demonstrates how manufacturing organizations can use
484 commercially available technologies that are consistent with cybersecurity standards to detect and
485 prevent cyber incidents on their ICS.

486 Manufacturers use a wide range of ICS equipment and manufacturing processes. This guide contains
487 four different example solutions that are applicable to a range of manufacturing environments, focusing
488 on discrete and continuous manufacturing processes.

489 This project provides example solutions, composed of the following capabilities, for manufacturing
490 environments:

- 491 ▪ application allowlisting
- 492 ▪ behavior anomaly detection (BAD)
- 493 ▪ file integrity
- 494 ▪ user authentication and authorization
- 495 ▪ remote access

496 1.2.1 Relevant Standards and Guidance

497 The solutions presented in this guide are consistent with the practices and guidance provided by the
498 following references.

- 499 ▪ NIST Special Publication (SP) 800-167: *Guide to Application Whitelisting* [\[2\]](#)
- 500 ▪ Department of Homeland Security, *Critical Manufacturing Sector Cybersecurity Framework*
501 *Implementation Guidance* [\[3\]](#)

- 502 ▪ Executive Order no. 13636: *Improving Critical Infrastructure Cybersecurity* [\[4\]](#)
- 503 ▪ NIST, *Framework for Improving Critical Infrastructure Cybersecurity* [\[5\]](#)
- 504 ▪ NIST Interagency Report (NISTIR) 8219: *Securing Manufacturing Industrial Control Systems: Behavioral Anomaly Detection* [\[6\]](#)
- 505
- 506 ▪ NIST Internal Report (NISTIR) 8183: *Cybersecurity Framework Manufacturing Profile* [\[7\]](#)
- 507 ▪ NISTIR 8089: *An Industrial Control System Cybersecurity Performance Testbed* [\[8\]](#)
- 508 ▪ NIST SP 800-53 Rev. 5: *Security and Privacy Controls for Federal Information Systems and Organizations* [\[9\]](#)
- 509
- 510 ▪ NIST SP 800-181: *National Initiative for Cybersecurity Education (NICE) Cybersecurity Workforce Framework* [\[10\]](#)
- 511
- 512 ▪ NIST Special Publication 1800-25: *Data Integrity: Identifying and Protecting Assets Against Ransomware and Other Destructive Events* [\[11\]](#)
- 513
- 514 ▪ NIST Interagency or Internal Report 7298 Rev 3: *Glossary of Key Information Security Terms* [\[12\]](#)
- 515 ▪ U.S.-Canada Power System Outage Task Force [\[13\]](#)
- 516 ▪ NIST SP 800-82 Rev. 2: *Guide to Industrial Control Systems (ICS) Security* [\[14\]](#)

517 1.3 Benefits

518 This NCCoE practice guide can help organizations:

- 519 ▪ mitigate cybersecurity risk
- 520 ▪ reduce downtime to operations
- 521 ▪ provide a reliable environment that can detect cyber anomalies
- 522 ▪ respond to security alerts through automated cybersecurity-event products
- 523 ▪ develop and execute an OT cybersecurity strategy for which continuous OT cybersecurity monitoring is a foundational building block
- 524
- 525 ▪ implement current cybersecurity standards and best practices

526 2 How to Use This Guide

527 This NIST Cybersecurity Practice Guide demonstrates a modular design and provides users with the
528 information they need to replicate the described manufacturing ICS security solutions, specifically
529 focusing on information and system integrity. This reference design is modular and can be deployed in
530 whole or in part.

531 This guide contains three volumes:

- 532 ▪ NIST SP 1800-10A: *Executive Summary*
- 533 ▪ NIST SP 1800-10B: *Approach, Architecture, and Security Characteristics* – what we built and why
534 **(this document)**
- 535 ▪ NIST SP 1800-10C: *How-To Guide* – instructions for building the example solution

536 Depending on your role in your organization, you might use this guide in different ways:

537 **Senior information technology (IT) executives, including chief information security and technology**
538 **officers**, will be interested in the *Executive Summary*, NIST SP 1800-10A, which describes the following
539 topics:

- 540 ▪ challenges that enterprises face in ICS environments in the manufacturing sector
- 541 ▪ example solution built at the NCCoE
- 542 ▪ benefits of adopting the example solution

543 **Technology or security program managers** might share the *Executive Summary*, NIST SP 1800-10A, with
544 your leadership to help them understand the importance of adopting a standards-based solution. Doing
545 so can strengthen their information and system integrity practices by leveraging capabilities that may
546 already exist within their operating environment or by implementing new capabilities.

547 **Technology or security program managers** who are concerned with how to identify, understand, assess,
548 and mitigate risk will be interested in NIST SP 1800-10B (this document), which describes what we did
549 and why. [Section 3.4.4](#), which maps the security characteristics of the example solutions to
550 cybersecurity standards and best practices, will be of particular interest:

- 551 ▪ **IT and OT professionals** who want to implement an approach like this will find the whole
552 practice guide useful, particularly the how-to portion, NIST SP 1800-10C, which provides step-
553 by-step details to replicate all, or parts of the example solutions created in our lab. Volume C
554 does not re-create the product manufacturers' documentation, which is generally widely
555 available. Rather, Volume C shows how we integrated the products together to create an
556 example solution.

557 This guide assumes that IT and OT professionals have experience implementing security products within
558 the enterprise. While we have used a suite of commercial products to address this challenge, this guide
559 does not endorse these particular products. Your organization can adopt this solution or one that
560 adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and
561 implementing parts of the manufacturing ICS solution. Your organization's security experts should
562 identify the products that will best integrate with your existing tools and IT system infrastructure. We
563 hope that you will seek products that are congruent with applicable standards and best practices.
564 [Section 3.5](#), Technologies, lists the products we used and maps them to the cybersecurity controls
565 provided by this reference solution.

566 A NIST Cybersecurity Practice Guide does not describe "the" solution. Every organization is unique in its
567 priorities, risk tolerance, and the cyber ecosystem they operate in. This document presents a possible
568 solution that may be tailored or augmented to meet an organization's own needs.

569 This document provides initial guidance. We seek feedback on its contents and welcome your input.
570 Comments, suggestions, and success stories will improve subsequent versions of this guide. Please
571 contribute your thoughts to manufacturing_nccoe@nist.gov.

572 2.1 Typographic Conventions

573 The following table presents typographic conventions used in this volume.

Typeface/Symbol	Meaning	Example
<i>Italics</i>	file names and path names; references to documents that are not hyperlinks; new terms; and placeholders	For language use and style guidance, see the <i>NCCoE Style Guide</i> .
Bold	names of menus, options, command buttons, and fields	Choose File > Edit .
Monospace	command-line input, onscreen computer output, sample code examples, and status codes	<code>mkdir</code>
Monospace Bold	command-line user input contrasted with computer output	service sshd start
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's NCCoE are available at https://www.nccoe.nist.gov .

574 3 Approach

575 This practice guide documents the approach the NCCoE used to develop example solutions, called
576 builds, supporting information and system integrity objectives. The approach includes a logical design,
577 example build development, testing, security control mapping, and analysis.

578 Based on our discussions with cybersecurity practitioners in the manufacturing sector, the NCCoE
579 pursued the Information and System Integrity in ICS Environments project to illustrate the broad set of
580 capabilities available to manage and protect OT assets.

581 The NCCoE collaborated with the NIST Engineering Lab (EL), Community of Interest (COI) members, and
582 the participating vendors to produce an example architecture and its corresponding implementations.
583 Vendors provided technologies that met project requirements and assisted in installation and
584 configuration of those technologies. This practice guide highlights the implementation of example
585 architectures, including supporting elements such as functional tests, security characteristic analysis,
586 and future build considerations

587 3.1 Audience

588 This guide is intended for individuals or entities responsible for cybersecurity of ICS and for those
589 interested in understanding information and system integrity capabilities for OT and how one
590 approaches the implementation of an architecture. It may also be of interest to anyone in industry,
591 academia, or government who seeks general knowledge of an OT information and system integrity
592 solution for manufacturing-sector organizations.

593 3.2 Scope

594 This document focuses on information and system integrity in ICS environments typical of
595 manufacturing organizations. It provides real-world guidance on implementing a solution for
596 manufacturing ICS environments.

597 The scope of this project is to protect the integrity of information and systems, which includes:

- 598 ▪ securing the data historians
- 599 ▪ preventing the execution or installation of unapproved software
- 600 ▪ detecting anomalous behavior on the network that affects system or information integrity
- 601 ▪ detecting hardware, software, or firmware modification
- 602 ▪ enabling secure remote access
- 603 ▪ authenticating and authorizing users

604 Organizational cybersecurity policies and procedures, as well as response and recovery functions, are
605 out of scope for this document.

606 The security capabilities used in this demonstration for protecting information and system integrity in
607 ICS environments are briefly described below. These capabilities are implemented using commercially
608 available third-party and open-source solutions that provide the following capabilities:

- 609 ▪ **Application Allowlisting (AAL):** A list of applications and application components (libraries,
610 configuration files, etc.) that are authorized to be present or active on a host according to a
611 well-defined baseline. [\[2\]](#)
- 612 ▪ **Behavioral Anomaly Detection:** A mechanism providing a multifaceted approach to detecting
613 cybersecurity attacks. [\[6\]](#)
- 614 ▪ **Hardware/Software/Firmware Modification Detection:** A mechanism providing the ability to
615 detect changes to hardware, software, and firmware on systems or network connected devices.
- 616 ▪ **File Integrity Checking:** A mechanism providing the ability to detect changes to files on systems
617 or network-connected devices.
- 618 ▪ **User Authentication and Authorization:** A mechanism for verifying the identity and the access
619 privileges granted to a user, process, or device. [\[12\]](#)
- 620 ▪ **Remote Access:** A mechanism supporting access to an organizational information system by a
621 user (or an information system acting on behalf of a user) communicating through an external
622 network (e.g., the Internet). [\[12\]](#)

623 3.3 Assumptions

624 This project makes the following assumptions:

- 625 ▪ Each solution is comprised of several readily available products. The modularity of the solutions
626 might allow organizations to consider swapping one or more products, depending on their
627 specific requirements.

- 628 ▪ A cybersecurity stakeholder might implement all or part of a solution in a manner that is
629 compatible with their existing environment.
- 630 ▪ Organizations will test and evaluate the compatibility of the solutions with their ICS devices
631 prior to production implementation and deployment. Response and recovery functions are
632 beyond the scope of this guide.

633 3.4 Risk Assessment

634 [NIST SP 800-30 Revision 1, Guide for Conducting Risk Assessments](#), states that risk is “a measure of the
635 extent to which an entity is threatened by a potential circumstance or event, and typically a function of:
636 (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of
637 occurrence.” The guide further defines risk assessment as “the process of identifying, estimating, and
638 prioritizing risks to organizational operations (including mission, functions, image, reputation),
639 organizational assets, individuals, other organizations, and the Nation, resulting from the operation of
640 an information system. Part of risk management incorporates threat and vulnerability analyses, and
641 considers mitigations provided by security controls planned or in place.”

642 The NCCoE recommends that any discussion of risk management, particularly at the enterprise level,
643 begins with a comprehensive review of [NIST SP 800-37 Revision 2, Risk Management Framework for
644 Information Systems and Organizations](#), material that is available to the public. The [Risk Management
645 Framework \(RMF\)](#) guidance, as a whole, proved to be invaluable in giving us a baseline to assess risks,
646 from which we developed the project, the security characteristics of the build, and this guide.

647 3.4.1 Threats

648 A threat is “any circumstance or event with the potential to adversely impact organizational operations”
649 [\[11\]](#). Within an IT environment, threats are typically thought of in terms of threats to confidentiality,
650 integrity, or availability.

651 The realization of a threat to confidentiality, integrity, and availability may have different impacts to the
652 OT versus the IT environments. OT environments are sensitive to loss of safety, availability, and
653 integrity, while traditional IT environments tend to direct more resources toward confidentiality.
654 Organizations that combine IT and OT operations are advised to evaluate the threats from both
655 perspectives.

656 In a cyber-physical system, cybersecurity stakeholders are advised to consider events that occur in the
657 OT environment may have impact to physical assets and events that occur in the physical world may
658 impact the OT environment. For example, in 2021 a ransomware attack against an American oil pipeline
659 system led to a disruption of operations and ultimately resulted in fuel shortages at airports and filling
660 stations on the United States east coast. At the time of this writing, a full assessment has not been
661 completed, but the economic impact to the pipeline was substantial.

662 An integrity loss need not be malicious to cause a significant impact. For example, a race condition in a
663 supervisory control and data acquisition (SCADA) program caused a loss of information integrity. This led
664 to alarm and notification failures and ultimately caused the Northeast Blackout of 2003. In excess of 55
665 million people were affected by this blackout and more than 100 people died. [\[13\]](#) Similarly, a sensor or
666 metrology malfunction can lead to corrupted values in databases, logs, or other repositories.

667 Examples of integrity loss that may have an impact on the physical system include:

- 668 ▪ Data corruption of alarm thresholds or control setpoints may lead to poor production quality in
669 products or, in the extreme case, damage and destruction to physical manufacturing equipment.
- 670 ▪ A loss of integrity of telemetry data may cause control algorithms to produce erroneous or even
671 detrimental commands to manufacturing or control equipment.
- 672 ▪ Corrupted routing tables or a denial-of-service attack on the communications infrastructure may
673 cause the manufacturing processes to enter into a fail-safe state, thus inhibiting production. If
674 the process is not designed to be fail-safe, an attack could result in equipment damage and lead
675 to a greater disaster.
- 676 ▪ Unauthorized remote access to the plant network could enable an attacker to stop production
677 or operate the plant and equipment beyond its intended operating range. An attacker
678 succeeding in disabling the safety instrument systems or changing its threshold parameters—
679 operating the plant beyond its intended range—could lead to severe equipment damage.

680 3.4.2 Vulnerabilities

681 A vulnerability as defined in [NISTIR 7298, Glossary of Key Information Security Terms \[12\]](#) is a “weakness
682 in an information system, system security procedures, internal controls, or implementation that could
683 be exploited by a threat source.”

684 As indicated in [Section 1](#) of this document, when IT and OT environments are integrated, each domain
685 inherits the vulnerabilities of the other. Increasing complexity of the interfaces typically results in the
686 vulnerability of the overall system being much greater than the sum of the vulnerabilities of the
687 subsystems.

688 [NIST SP 800-82](#) categorizes ICS vulnerabilities into the following categories with examples [\[14\]](#):

- 689 ▪ **Policy and Procedure:** incomplete, inappropriate, or nonexistent security policy, including its
690 documentation, implementation guides (e.g., procedures), and enforcement
- 691 ▪ **Architecture and Design:** design flaws, development flaws, poor administration, and
692 connections with other systems and networks
- 693 ▪ **Configuration and Maintenance:** misconfiguration and poor maintenance
- 694 ▪ **Physical:** lack of or improper access control, malfunctioning equipment
- 695 ▪ **Software Development:** improper data validation, security capabilities not enabled, inadequate
696 authentication privileges
- 697 ▪ **Communication and Network:** nonexistent authentication, insecure protocols, improper firewall
698 configuration

699 The first step in understanding the vulnerabilities and securing an organization’s ICS infrastructure is
700 knowledge of deployed assets and their interfaces. The knowledge of an asset’s location and baselining
701 of its behavior enable detection of anomalous behavior, via network monitoring, that may be the result
702 of a successfully exploited vulnerability. The ability to reliably detect changes in asset behavior and
703 knowing an asset’s attributes are key in responding to potential cybersecurity incidents.

704 3.4.3 Risk

705 The risk to an organization is the intersection of:

- 706 ▪ the vulnerabilities and threats to the organization
- 707 ▪ the likelihood that the vulnerability and threat event will be realized
- 708 ▪ the impact to the organization should the event be realized

709 A meaningful risk assessment must be performed in the context of the cyber-ecosystem and the impact
710 to an organization should a loss or degradation occur. The usefulness of the risk assessment is limited by
711 how well the organization identifies and prioritizes the criticality of its assets, identifies the threats, and
712 estimates the likelihood of the threats being realized.

713 Though risk analysis is a mature discipline, careful deliberations and analyses are necessary to determine
714 the effect integrating IT and OT assets has on the threats, vulnerabilities, and impact to the organization.
715 Once a baseline risk assessment has been completed, information assurance controls, such as the
716 integrity protection measures investigated in this project, can be evaluated on how well they reduce the
717 likelihood of the threat and subsequent reduction of risk. Cybersecurity stakeholders are strongly
718 encouraged to leverage the NIST *Cybersecurity Framework* and manufacturing overlays to identify the
719 components, elements, or items for which a risk assessment must be conducted. In addition, [NIST SP
720 800-82 \[14\]](#) mentions special considerations for performing an ICS risk assessment.

721 3.4.4 Security Control Map

722 Implementation of cybersecurity architectures is most effective when executed in the context of an
723 overall cybersecurity framework. Frameworks include a holistic set of activities or functions (i.e., what
724 needs to be done) and a selection of controls (i.e., how these are done) that are appropriate for a given
725 cyber-ecosystem. For this project, the NIST *Cybersecurity Framework* provided the overarching
726 framework.

727 The subset of NIST *Cybersecurity Framework* Functions, Categories, and Subcategories that are
728 supported by this example solution are listed below in [Table 3-1](#), along with the subset of mappings to
729 [NIST SP 800-53 Rev. 5](#) and to the [National Initiative for Cybersecurity Education \(NICE\) Workforce
730 Framework](#). [NIST SP 800-53 Rev 5: Security and Privacy Controls for Information Systems and
731 Organizations](#) provides a list of controls for protecting operations, assets, and individuals. The controls
732 detail requirements necessary to meet organizational needs. The [NICE Cybersecurity Workforce
733 Framework](#) identifies knowledge, skills, and abilities (KSAs) needed to perform cybersecurity tasks. It is a
734 reference guide on how to recruit and retain talent for various cybersecurity roles.

735 For more information on the security controls, the *NIST SP 800-53 Rev.5, Security and Privacy Controls
736 for Information Systems and Organizations* is available at
737 <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-53r5.pdf>.

738 For more information about NICE and resources that are available to employers, education and training
739 providers, students, and job seekers, the *NIST SP-181 Rev. 1, NICE Cybersecurity Workforce Framework*,
740 and other NICE resources are available at [https://nist.gov/it/applied-cybersecurity/nice/nice-
741 framework-resource-center](https://nist.gov/it/applied-cybersecurity/nice/nice-framework-resource-center).

742 Table 3-1: Security Control Map

Function	Category	Subcategory	NIST SP 800-53 Rev. 5	NIST SP 800-181 Rev. 1 (NICE Framework) Work Roles
PROTECT (PR)	Identity Management, Authentication, and Access Control (PR.AC): Access to physical and logical assets and associated facilities is limited to authorized users, processes, and devices, and is managed consistent with the assessed risk of unauthorized access to authorized activities and transactions.	PR.AC-1: Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes	IA-2, IA-4, IA-5, IA-7, IA-9, IA-10, IA-12	SP-DEV-001, OM-ADM-001, OV-PMA-003
		PR.AC-3: Remote access is managed	AC-17, AC-19	SP-SYS-001, OM-ADM-001, PR-INF-001
		PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties	AC-2, AC-3, AC-14, AC-24	OM-STS-001, OM-ADM-001
		PR.AC-7: Users, devices, and other assets are authenticated (e.g., single-factor, multi-factor) commensurate with the risk of the transaction (e.g., individuals' security and privacy risks and other organizational risks)	AC-14, IA-2, IA-4, IA-5	OM-STS-001, OM-ADM-001
	Data Security (PR.DS): Information and records (data) are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of information.	PR.DS-1: Data-at-rest is protected	MP-7, SC-28	SP-DEV-002, SP-SYS-002, OM-DTA-001
		PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity	SI-7	OM-DTA-001
	Information Protection Processes and Procedures (PR.IP): Security policies (that address purpose, scope, roles, responsibilities, management commitment, and coordination among organizational entities), processes,	PR.IP-4: Backups of information are conducted, maintained, and tested	CP-9	SP-SYS-001, SP-SYS-002, OM-DTA-001

Function	Category	Subcategory	NIST SP 800-53 Rev. 5	NIST SP 800-181 Rev. 1 (NICE Framework) Work Roles
PROTECT	and procedures are maintained and used to manage protection of information systems and assets.			
	Maintenance (PR.MA): Maintenance and repairs of industrial control and information system components is performed consistent with policies and procedures.	PR.MA-1: Maintenance and repair of organizational assets are performed and logged, with approved and controlled tools	MA-3	SP-SYS-001, OM-ANA-001
		PR.MA-2: Remote maintenance of organizational assets is approved, logged, and performed in a manner that prevents unauthorized access.	MA-4	SP-SYS-001, OM-ANA-001
DETECT (DE)	Anomalies and Events (DE.AE): Anomalous activity is detected in a timely manner and the potential impact of events is understood.	DE.AE-1: A baseline of network operations and expected data flows for users and systems is established and managed	CM-2, SI-4	SP-ARC-001, PR-CDA-001
		DE.AE-2: Detected events are analyzed to understand attack targets and methods	CA-7, SI-4, RA-5	OM-DTA-002, PR-CDA-001, CO-OPS-001
		DE.AE-3: Event data are collected and correlated from multiple sources and sensors	CA-7, SI-4	OM-DTA-002, PR-CDA-001, PR-CIR-001, CO-OPS-001
	Security Continuous Monitoring (DE.CM): The information system and assets are monitored at discrete intervals to identify cybersecurity events and verify the effectiveness of protective measures.	DE.CM-1: The network is monitored to detect potential cybersecurity events	AU-12, CA-7, CM-3, SC-7, SI-4	OM-NET-001, PR-CDA-001, PR-CIR-001
		DE.CM-3: Personnel activity is monitored to detect potential cybersecurity events	AU-12, CA-7, CM-11	PR-CDA-001, AN-TWA-001
		DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed	AU-12, CA-7, CM-3, SI-4	PR-CDA-001, PR-CIR-001, AN-TWA-001, CO-OPS-001

743 **3.5 Technologies**

744 [Table 3-2](#) lists the capabilities demonstrated in this project, the products, and their functions, along with
 745 a mapping of the capabilities to the NIST *Cybersecurity Framework*. Refer to [Table 3-1](#) for an explanation
 746 of the NIST *Cybersecurity Framework* subcategory codes.

747 **Table 3-2: Products and Technologies**

Capability	Product	Function	NIST <i>Cybersecurity Framework</i> Subcategories Mapping
Application Allowlisting (AAL)	VMWare Carbon Black	Allow approved ICS applications to execute.	DE.AE-2, DE.AE-3, DE.CM-3, DE.CM-7
	Windows Software Restriction Policies (SRP) (Note: This component was not provided by collaborator. It is a feature of the Windows operating system product.)		
File Integrity Checking	GreenTec WORMdisk and ForceField	Provides immutable storage for data, system, and configuration files.	PR.DS-1, PR.IP-4, PR.MA-1
	VMWare Carbon Black	Provides integrity checks for files and software.	PR.DS-6, PR.MA-1, DE.AE-2, DE.CM-3
	Wazuh Security Onion (Note: This component was not provided by collaborator. It is an open source product.)		
BAD, Hardware/ Software/ Firmware Modification Detection	Microsoft Azure Defender for IoT	Passively scans the OT network to create a baseline of devices and network traffic.	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
	Dragos Platform		
	Forescout eyeInspect (formerly SilentDefense)	Alerts when activity deviates from the baseline.	
	Tenable Tenable.ot		

Capability	Product	Function	NIST Cybersecurity Framework Subcategories Mapping
	PI System	Collects, analyzes, and visualizes time-series data from multiple sources. Alerts when activity deviates from the baseline.	PR.IP-4, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3
User Authentication and User Authorization	TDi ConsoleWorks	Provides a central location for managing password changes.	PR.AC-1, PR.AC-3, PR.AC-4, PR.MA-1, PR.MA-2, DE.AE-2, DE.AE-3, DE.CM-3, DE.CM-7
	Dispel	Provides a security perimeter for all devices within the OT environment.	
Remote Access	Dispel	Provides secure remote access. Records and logs user activity for each session.	PR.AC-3, PR.MA-2, DE.AE-2, DE.CM-7
	Cisco AnyConnect (Note: This component was not provided by collaborator. It was a component of the existing lab infrastructure.)		

748 4 Architecture

749 These mechanisms and technologies were integrated into the existing NIST Cybersecurity for Smart
750 Manufacturing Systems (CSMS) lab environment [8]. This cybersecurity performance testbed for ICS is
751 comprised of the Process Control System (PCS) and the Collaborative Robotic System (CRS) ICS
752 environments along with additional networking capabilities to emulate common manufacturing
753 environments.

754 Typically, manufacturing organizations have unique cyber-ecosystems and specific needs for their
755 operation. To demonstrate the modularity and interoperability of the provided solutions, this project
756 used available CRADA partner technologies to assemble four “builds” deployed across both the PCS and
757 CRS. Additionally, to increase the diversity of technologies between builds, two of the builds also utilized
758 open source solutions (Security Onion Wazuh), native operating system features (Windows Software
759 Restriction Policies [SRP]), and a Cisco Adaptive Security Appliance (ASA) device configured with the
760 AnyConnect VPN client.

761 This modular approach, focusing on specific products and outcomes, demonstrates how solutions might
762 be tailored to the operating environment. [Table 4-1](#) provides a summary of the four builds and how the

763 products were distributed across them. Detailed descriptions of the installation, configuration, and
 764 integration of these builds are included in Volume C of this guide.

765 **Table 4-1: Summary of What Products Were Used in Each Build**

Capability	Build 1	Build 2	Build 3	Build 4
	PCS		CRS	
Application Allowlisting	Carbon Black	Windows SRP	Windows SRP	Carbon Black
Behavior Anomaly Detection , Hardware/Software/Firmware Modification Detection	PI Server	PI Server	PI Server	PI Server
	Tenable.ot	eyeInspect	Dragos	Azure Defender for IoT
File Integrity Checking	Carbon Black	Wazuh	Wazuh	Carbon Black
	ForceField, WORMdisk	ForceField, WORMdisk	ForceField, WORMdisk	ForceField, WORMdisk
User Authentication and Authorization	ConsoleWorks	Dispel	ConsoleWorks	Dispel
Remote Access	AnyConnect	Dispel	AnyConnect	Dispel

766 [Sections 4.1, 4.2, 4.3, and 4.4](#), present descriptions of the manufacturing processes and control systems
 767 of the testbed that are used for demonstrating the security capabilities required for protecting
 768 information and system integrity in ICS environments. [Section 4.5](#) describes the network and security
 769 architectures that are used to implement the above security capabilities.

770 **4.1 Manufacturing Process and Control System Description**

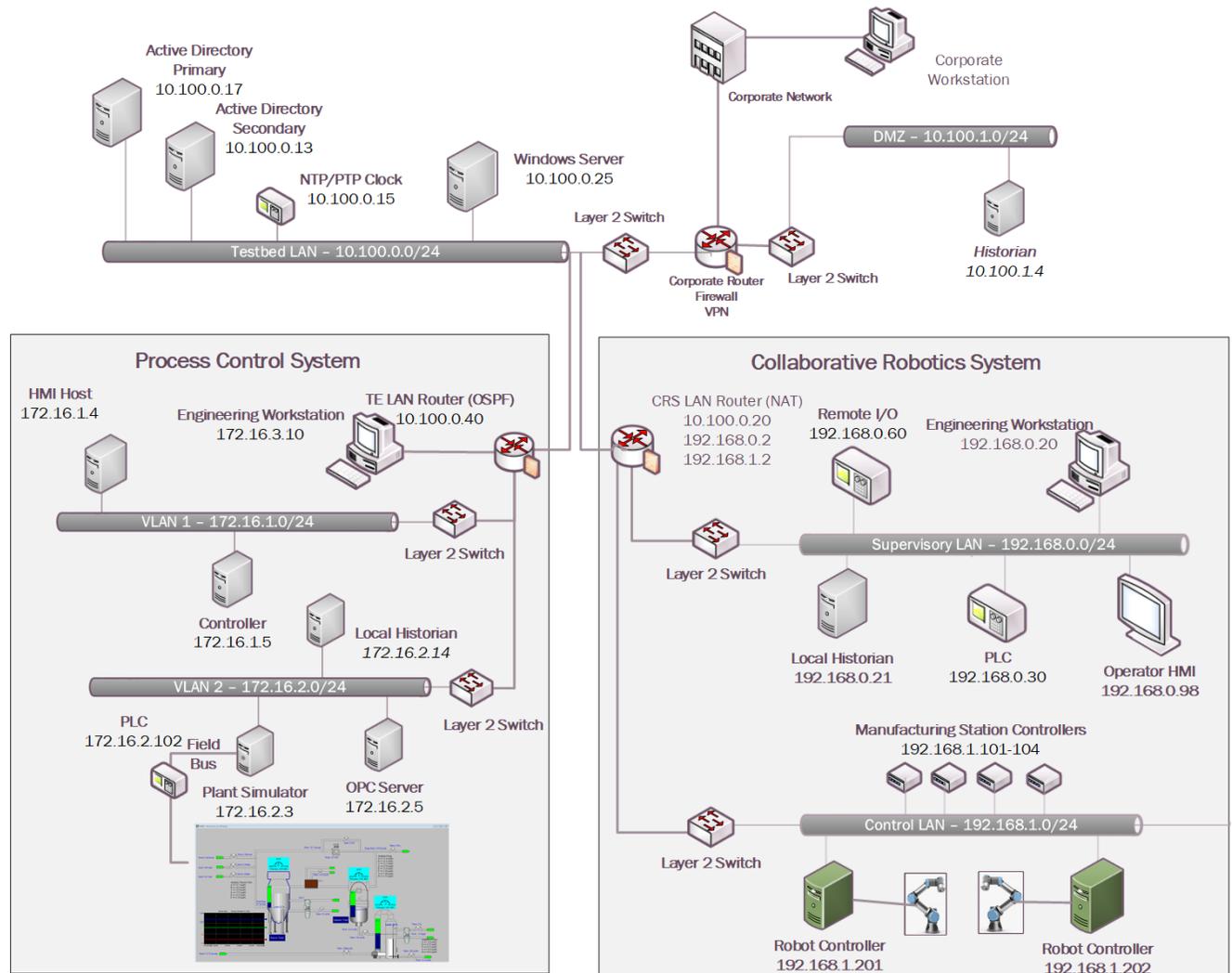
771 The CSMS demonstration environment emulates real-world manufacturing processes and their ICS by
 772 using software simulators and commercial off-the-shelf (COTS) hardware in a laboratory environment
 773 [\[8\]](#). The CSMS environment was designed to measure the performance impact on ICS that is induced by
 774 cybersecurity technologies. For this effort, the CSMS and the integrated PCS and CRS are used to
 775 demonstrate the information and system integrity capabilities and are described in [Sections 4.3](#) and [4.4](#).

776 **4.2 Cybersecurity for Smart Manufacturing Systems Architecture**

777 [Figure 4-1](#) depicts a high-level architecture for the demonstration environment consisting of a testbed
 778 local area network (LAN), a demilitarized zone (DMZ), the PCS, and the CRS. The environment utilizes a
 779 combination of physical and virtual systems and maintains a local network time protocol (NTP) server
 780 for time synchronization. Additionally, the environment utilizes virtualized Active Directory (AD) servers
 781 for domain services. The tools used to support information and system integrity are deployed and

782 integrated in the DMZ, Testbed LAN, PCS, and CRS according to vendor recommendations and standard
 783 practices as described in the detailed sections for each build.

784 **Figure 4-1: CSMS Network Architecture**



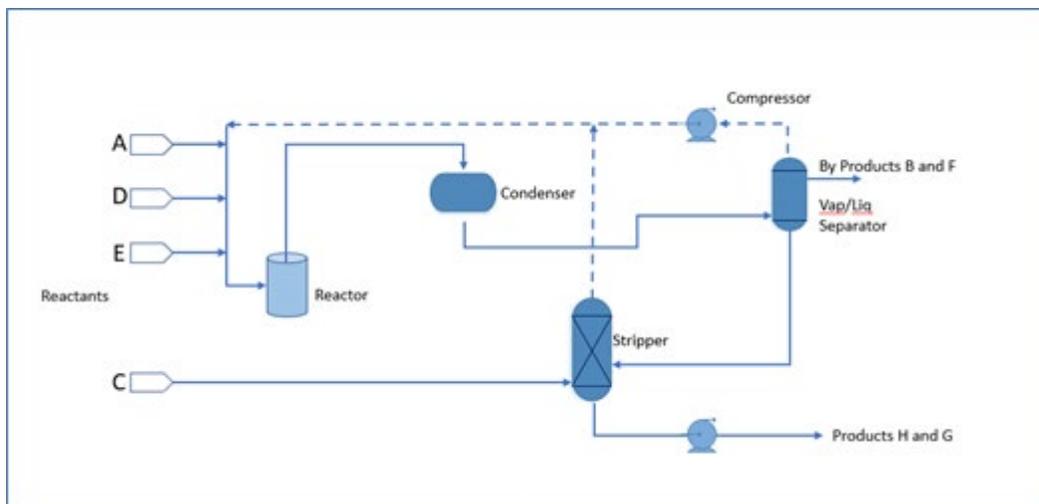
785 **4.3 Process Control System**

786 A continuous manufacturing process is a type of manufacturing process that produces or processes
 787 materials continuously and in which the materials are continuously moving, going through chemical
 788 reactions, or undergoing mechanical or thermal treatment. Continuous manufacturing usually implies a
 789 24-hours a day, seven days a week (24/7) operation with infrequent maintenance shutdowns. Examples
 790 of continuous manufacturing systems are chemical production, oil refining, natural gas processing, and
 791 wastewater treatment.

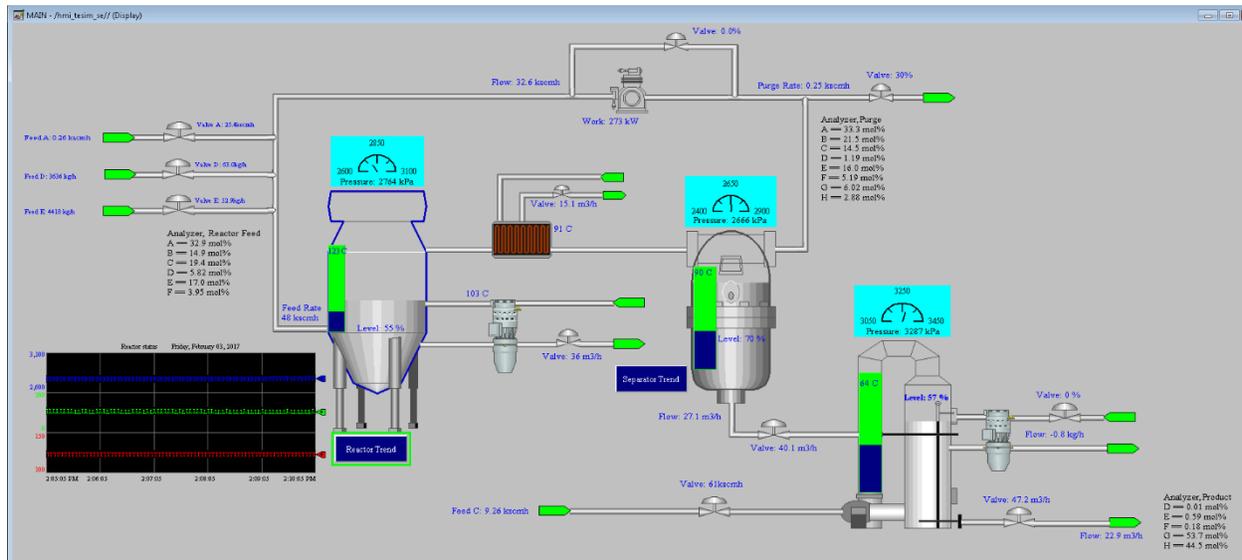
792 The PCS emulates the Tennessee-Eastman (TE) chemical reaction process. The TE problem, presented by
793 Downs and Vogel [15], is a well-known process-control problem in continuous chemical manufacturing.
794 A control loop is required in the PCS to maintain a steady and stable chemical production. The PCS
795 presents a real-world scenario in which a cybersecurity attack could represent a real risk to human
796 safety, environmental safety, and economic viability. This allows the PCS to be used to assess the impact
797 of cybersecurity attacks on the continuous process manufacturing environment.

798 The PCS includes a software simulator to emulate the TE chemical reaction process. The simulator is
799 written in C code and is executed on a workstation-class computer. In addition, the system includes a
800 series of COTS hardware, including an Allen-Bradley ControlLogix 5571 PLC, a software controller
801 implemented in MATLAB for process control, a Rockwell FactoryTalk Human Machine Interface(HMI), an
802 object linking and embedding for process control (OPC) data access (DA) server, a data historian, an
803 engineering workstation, and several virtual LAN (VLAN) switches and network routers. Figure 4-2 and
804 [Figure 4-3](#) outline the process flow of the TE manufacturing process. The simulated TE process includes
805 five major units with multiple input feeds, products, and byproducts that has 41 measured variables
806 (sensors) and 12 manipulated variables (actuators). The PCS consists of a software simulated chemical
807 manufacturing process (TE process), integrated with a series of COTS hardware, including PLCs,
808 industrial network switches, protocol converters, and hardware modules to connect the simulated
809 process and the control loop.

810 **Figure 4-2: Simplified Tennessee Eastman Process Model**



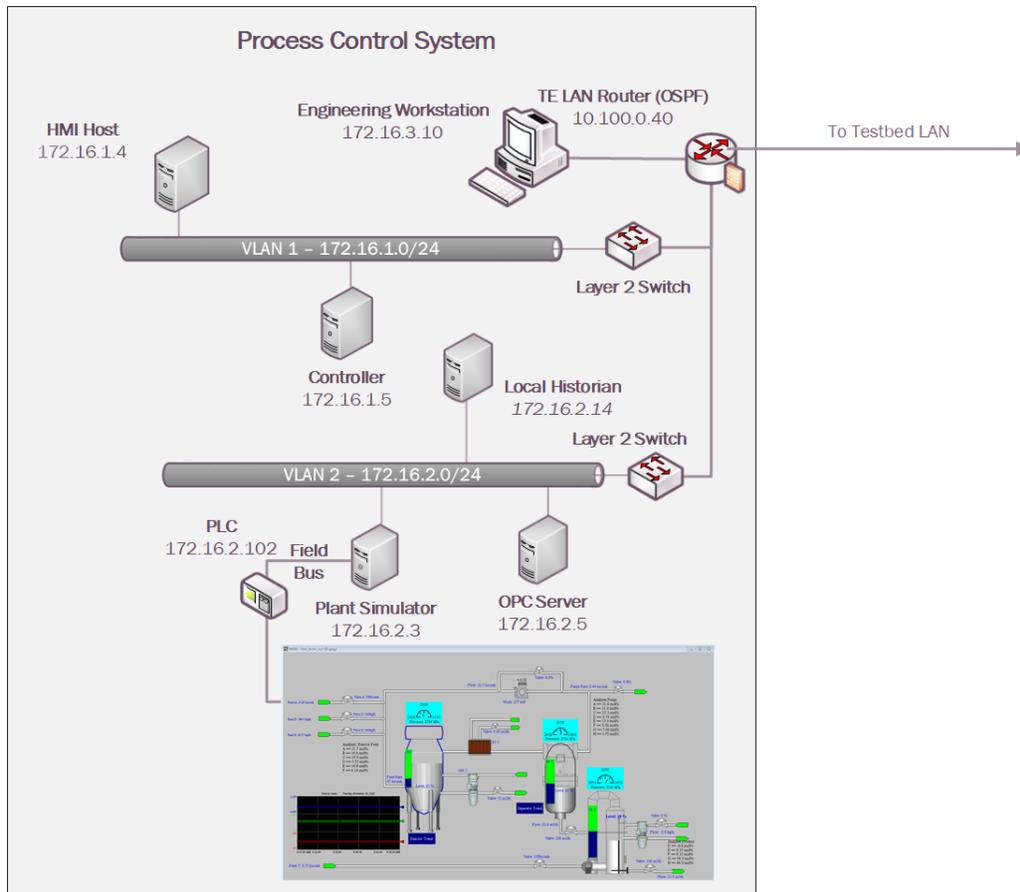
811 Figure 4-3: HMI Screenshot for the PCS Showing the Main Components in the Process



812 The PCS network architecture is shown in [Figure 4-4](#). The PCS network is connected to the Testbed LAN
 813 via a boundary router. The boundary router is an Allen-Bradley Stratix 8300. All network traffic is going
 814 through the boundary router to access the Testbed LAN and the DMZ. The PCS environment is
 815 segmented into three local networks, namely the engineering LAN, Operations LAN (VLAN1), and the
 816 Supervisory LAN (VLAN2). Each of these local networks is connected using an industrial network switch,
 817 an Allen-Bradley Stratix 5700. The engineering workstation is hosted in the engineering LAN. The HMI
 818 and the Plant Controller are hosted in the operations LAN. The Plant Simulator is hosted in the
 819 supervisory LAN along with the Local Historian, OPC Server, and the Supervisory PLC.

820 The Operations LAN (VLAN1) simulates a central control room environment. The supervisory LAN
 821 (VLAN2) simulates the process operation/ manufacturing environment, which typically consists of the
 822 operating plant, PLCs, OPC server, and data historian.

823 An OPC DA server is the main data gateway for the PLC and the simulated controller. The PLC reads in
 824 the manufacturing process sensor data from the Plant Simulator using the DeviceNet connection and
 825 communicates the data to the OPC DA server. The PLC also retrieves actuator information from the
 826 controller through the OPC DA and transmits to the Plant Simulator. The controller uses a MATLAB
 827 Simulink interface to communicate with the OPC DA server directly.

828 **Figure 4-4: PCS Network**829 **4.4 Collaborative Robotics System (CRS)**

830 The CRS workcell, shown in [Figure 4-5](#), contains two robotic arms that perform a material handling
 831 process called machine tending [8]. Robotic machine tending utilizes robots to interact with machinery,
 832 performing physical operations a human operator would normally perform (e.g., loading and unloading
 833 of parts in a machine, opening and closing of machine doors, activating operator control panel buttons,
 834 etc.).

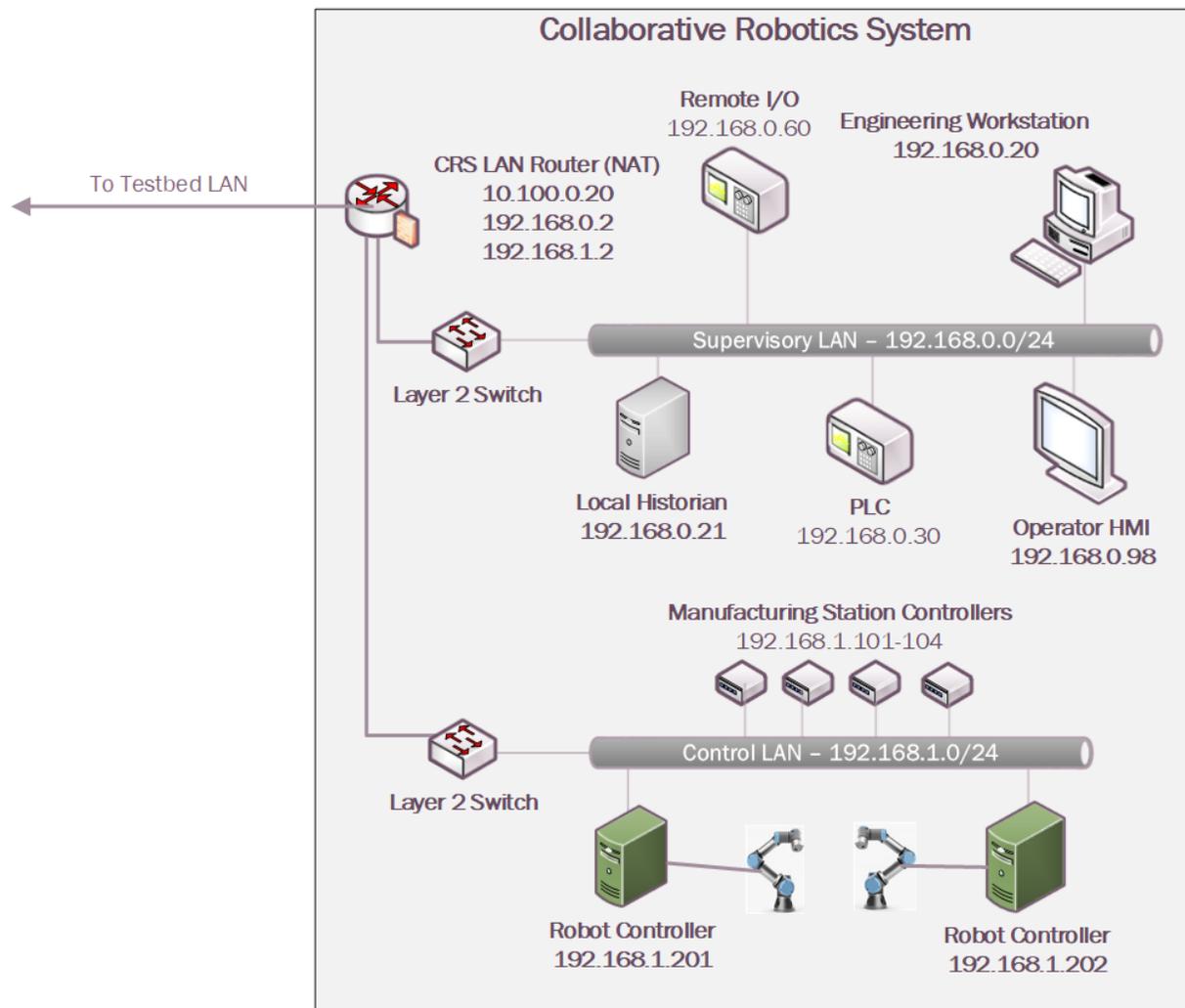
835 Parts are transported by two Universal Robots UR3e robotic arms through four simulated machining
 836 stations. Each station communicates with the Supervisory PLC (a Beckhoff CX9020) over the workcell
 837 network, which monitors and controls all aspects of the manufacturing process. An HMI (Red Lion G310)
 838 allows the workcell operator to monitor and control process parameters.

839 Figure 4-5: The CRS Workcell



840 The CRS network, shown in [Figure 4-6](#), is hierarchically architected, separating the supervisory devices
841 from the low-level OT that control the manufacturing process. The top-level router is a Siemens
842 RUGGEDCOM RX1510, which provides firewall capabilities, logical access to the Testbed LAN network,
843 network address translation (NAT), and other cybersecurity capabilities. The router is connected to the
844 Testbed LAN (identified in [Figure 4-1](#) as the Testbed LAN) using NAT. Layer 2 network traffic for the
845 Supervisory LAN is handled by a Netgear GS724T-managed Ethernet switch, and network traffic for the
846 Control LAN is handled by a Siemens i800-managed Ethernet switch.

847 Figure 4-6: CRS Network



848 4.5 Logical Network and Security Architectures

849 The following sections provide a high-level overview of the technology integration into the ICS
 850 environments for each solution, also referred to as a build. Additional details related to the installation
 851 and configuration of these tools are provided in Volume C of this guide.

852 4.5.1 Build 1

853 For Build 1, the technologies in [Table 4-2](#) were integrated into the PCS environment, Testbed LAN, and
 854 DMZ segments of the testbed environment to enhance system and information integrity capabilities.

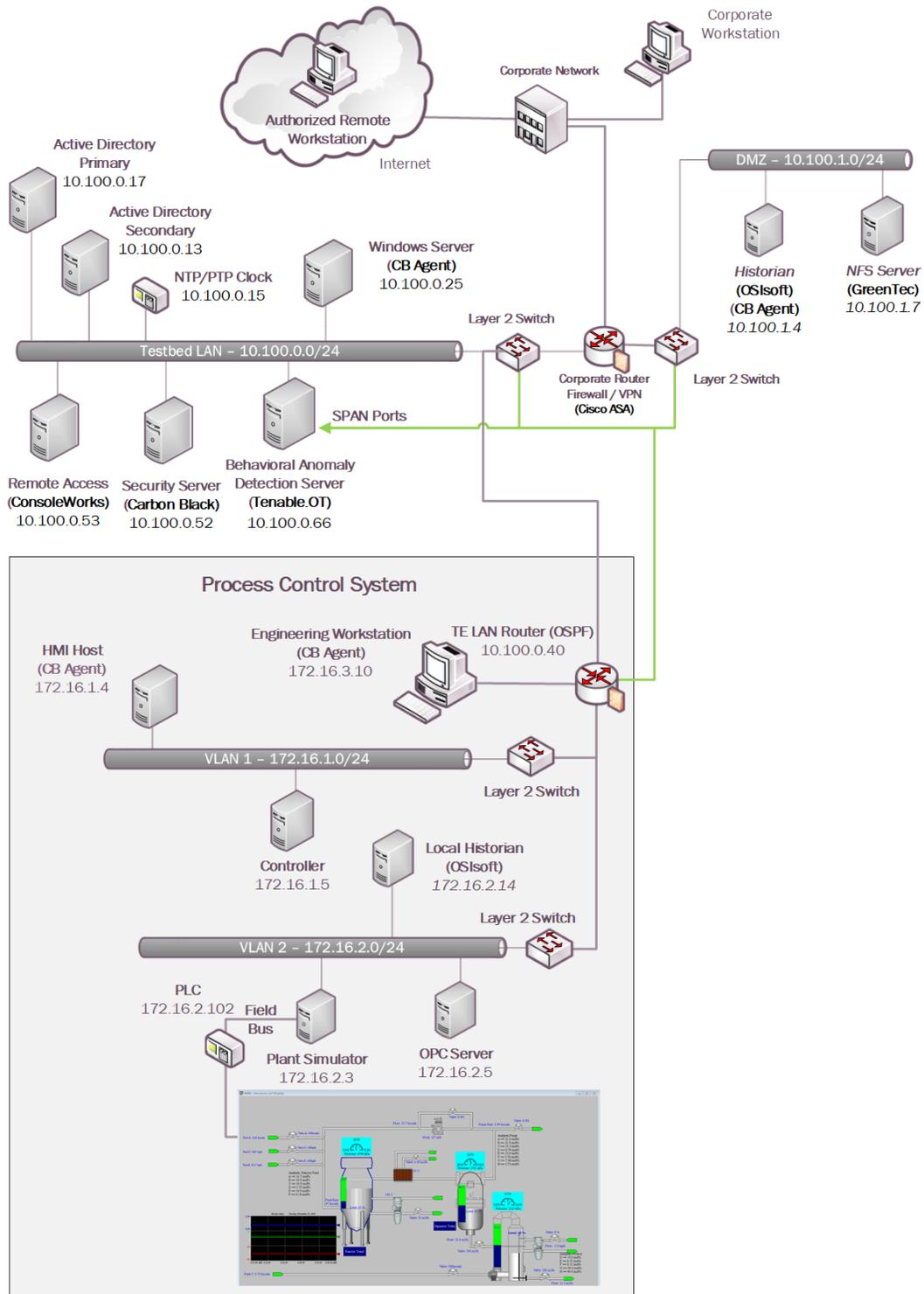
855 Table 4-2: Build 1 Technology Stack to Capabilities Map

Capability	Products	Description
Application Allowlisting	Carbon Black	Carbon Black Server is deployed within the Testbed LAN with the Carbon Black Agents installed on key workstations and servers in the Testbed LAN, PCS environment, and DMZ to control application execution.
Behavior Anomaly Detection, Hardware/Software/Firmware Modification Detection	PI Server	Deployed in the DMZ and PCS environments, the PI Server provides the historian repository for process data through its Data Archive and generates Event Frames upon detection of abnormal manufacturing system behavior.
	Tenable.ot	Passively monitors the PCS network, Testbed LAN, and DMZ for abnormal network activity via SPAN ports, and is also configured to capture detailed asset information for supporting inventory, change via both passive and active scanning.
File Integrity Checking	Carbon Black	Deployed within the Testbed LAN environment with the Carbon Black Agents installed on key workstations and servers to monitor the integrity of local files.
	ForceField, WORMdisk	A GreenTec fileserver is added to the DMZ environment and configured with both a ForceField and WORM drive to provide a protected archive for the historian data and the approved versions of configuration, source (PLC Programs), and executable files for the ICS environment.
User Authentication and Authorization	ConsoleWorks	Deployed to centralize the access and management of the systems and credentials. ConsoleWorks is deployed to the Testbed LAN to allow connections to the PCS environment.

Capability	Products	Description
Remote Access	AnyConnect	Supports authenticated VPN connections to the environment with limited access to only the TDI ConsoleWorks web interface.

The technology was integrated into the lab environment as shown in [Figure 4-7](#).

856 Figure 4-7: Build 1, PCS Complete Architecture with Security Components



857 **4.5.2 Build 2**

858 For Build 2, the technologies in Table 4-3 were integrated into the PCS, Testbed LAN, and DMZ segments
 859 of the testbed environment to enhance system and information integrity capabilities.

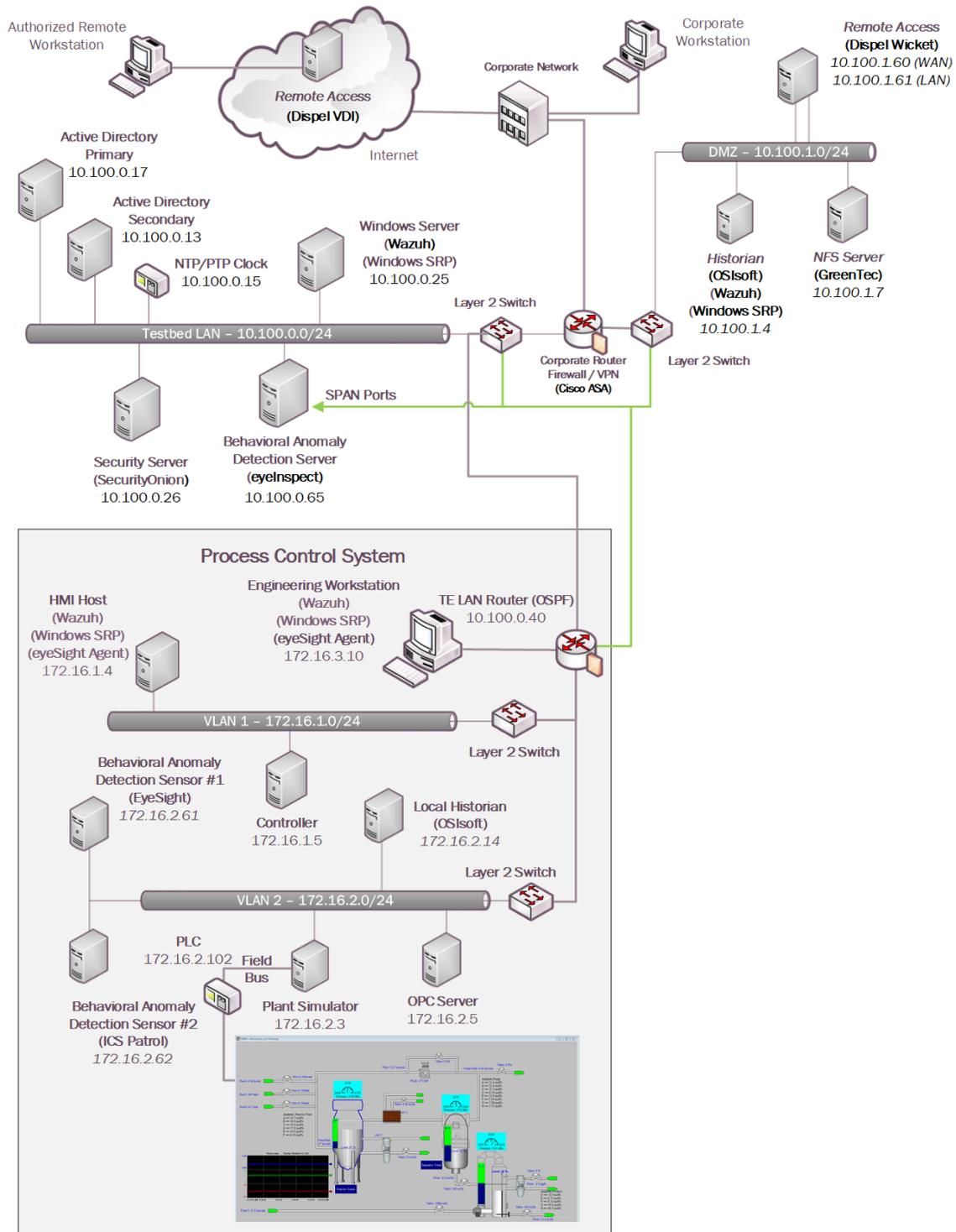
860 **Table 4-3: Build 2 Technology Stack to Capabilities Map**

Capability	Product	Description
Application Allowlisting	Windows SRP	AD Group Policy Objects (GPOs) are used to configure and administer the Windows Software Restriction Policy (SRP) capabilities within the Testbed LAN environment and PCS environments. For non-domain systems (e.g., Dispel VDI and DMZ systems), the GPO was applied as local settings on the systems.
Behavior Anomaly Detection, Hardware/Software/Firmware Modification Detection	PI Server	Deployed in the DMZ and PCS environments, the PI Server provides the historian repository for process data through its Data Archive and generates Event Frames upon detection of abnormal manufacturing system behavior.
	eyeInspect ICSPatrol	Passively monitors the PCS network, Testbed LAN, and DMZ for abnormal network activity via SPAN ports, and is also configured to capture detailed asset information for supporting inventory and change management capabilities using the ICSPatrol server, which can perform scans on ICS components.
File Integrity Checking	Wazuh	The Security Onion server is used to manage and monitor the integrity of local files using the Wazuh agents deployed on the Dispel VDI, DMZ, Testbed LAN, and PCS.
	ForceField, WORMdisk	A GreenTec fileserver is added to the DMZ environment and configured with both a ForceField and WORM drive to provide a protected archive for the historian data and the approved versions of configuration, source, and executable files for the ICS environment.

Capability	Product	Description
User Authentication and Authorization	Dispel	The Dispel Wicket is deployed to the DMZ environment and integrated with the Dispel cloud-based environment to provide a virtual desktop interface (VDI) with a secure remote connection to the testbed environment. Through this connection, authorized users are permitted to access resources in both the Testbed LAN and PCS environment.
Remote Access		

861 The technology was integrated into the lab environment as shown in [Figure 4-8](#).

862 Figure 4-8: Build 2, PCS Complete Architecture with Security Components



863 4.5.3 Build 3

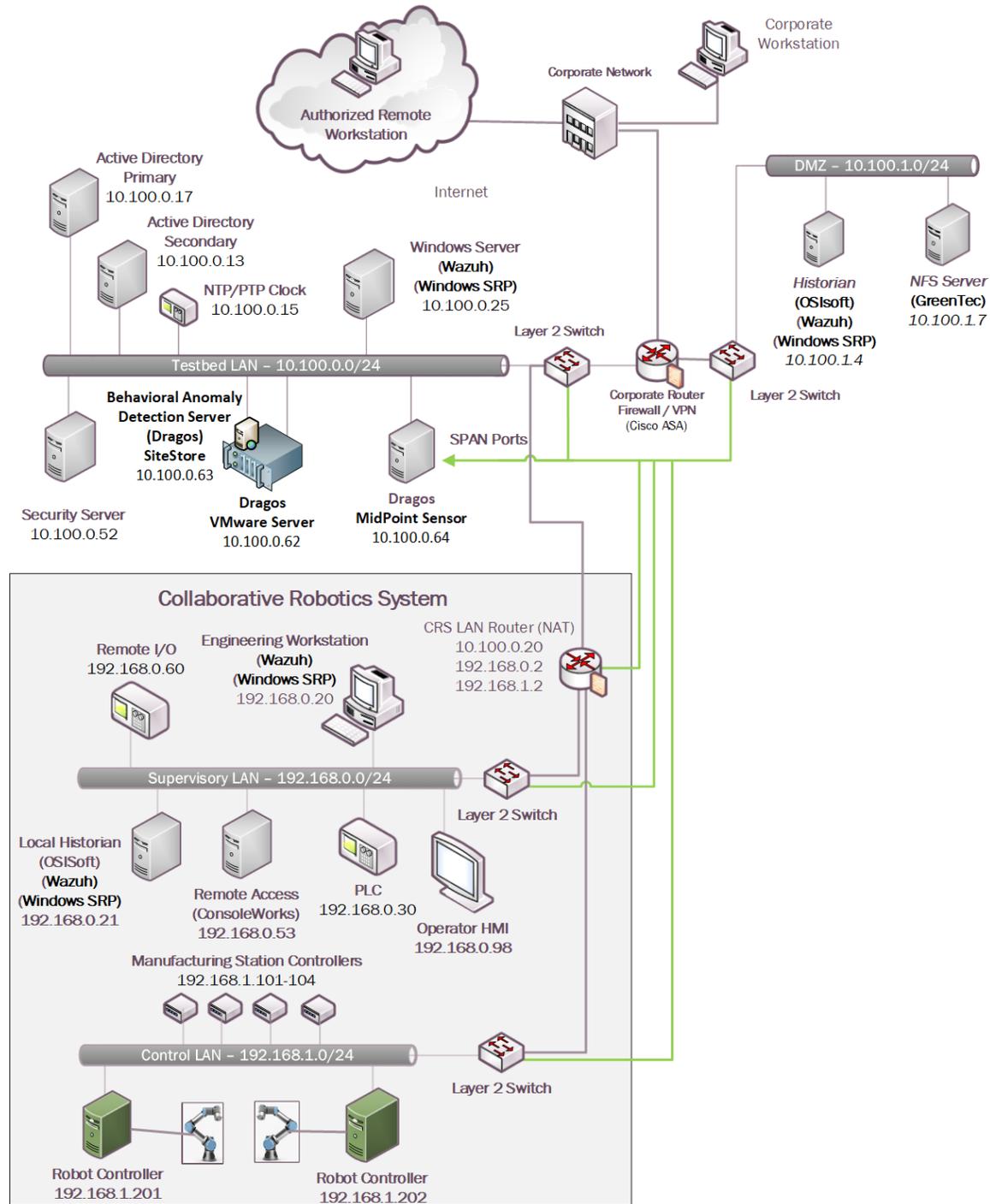
864 The technologies in Table 4-4 were integrated into the CRS for Build 3 to enhance system and data
 865 integrity capabilities.

866 Table 4-4: Build 3 Technology Stack to Capabilities Map

Capability	Products	Description
Application Allowlisting	Windows SRP	AD Group Policy Objects (GPOs) are used to configure and administer the Windows Software Restriction Policy (SRP) capabilities within the Testbed LAN environment and CRS environments.
Behavior Anomaly Detection, Hardware/Software/Firmware Modification Detection	PI Server	Deployed in the DMZ and CRS environments, the PI Server provides the historian repository for process data through its Data Archive and generates Event Frames upon detection of abnormal manufacturing system behavior
	Dragos	Passively monitors the CRS network, Testbed LAN, and DMZ for abnormal network activity via SPAN ports and receives Event Frames from the DMZ PI system through the PI Web API interface.
File Integrity Checking	Wazuh	The Security Onion server is used to manage and monitor the integrity of local files using the Wazuh agents deployed on the DMZ, Testbed LAN, and CRS.
	ForceField, WORMdisk	A GreenTec fileserver is added to the DMZ environment and configured with both a ForceField and WORM drive to provide a protected archive for the historian data and the approved versions of configuration and coding files for the ICS environment.
User Authentication and Authorization	ConsoleWorks	Deployed to centralize the access and management of the systems and credentials. ConsoleWorks is deployed to allow connections within the CRS environment.
Remote Access	AnyConnect	Supports authenticated VPN connections to the environment with limited access to only the TDI ConsoleWorks web interface.

867 The technology was integrated into the lab environment as shown in Figure 4-9.

868 Figure 4-9: Build 3, CRS Complete Architecture with Security Components



869 **4.5.4 Build 4**

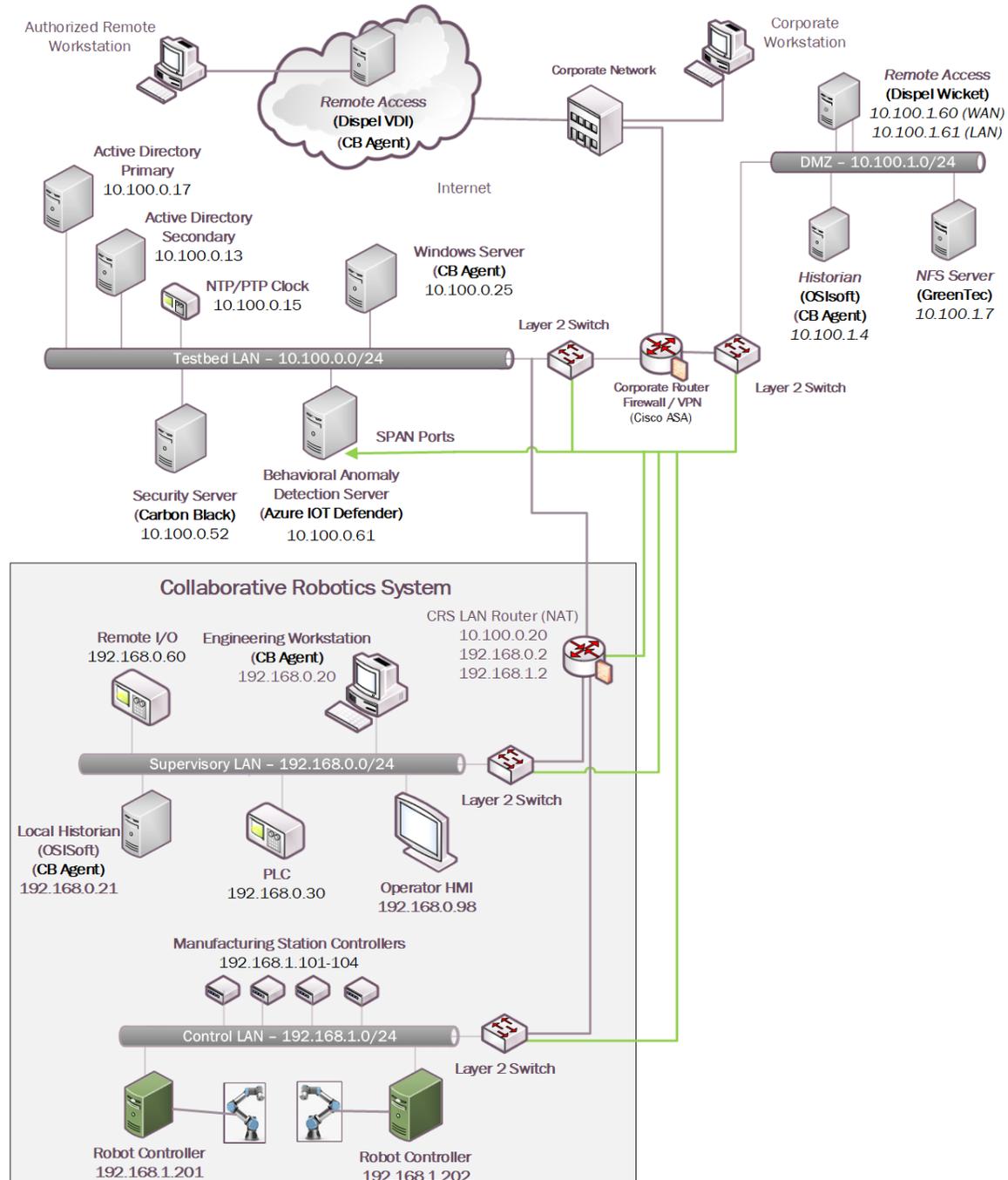
870 For Build 4, the technologies in Table 4-5 were integrated into the CRS, Testbed LAN, and DMZ segments
 871 of the testbed environment to enhance system and data integrity capabilities.

872 **Table 4-5: Build 4 Technology Stack to Capabilities Map**

Capability	Products	Description
Application Allowlisting	Carbon Black	Deployed within the Testbed LAN environment with the Carbon Black agents installed on key workstations and servers to control application execution.
Behavior Anomaly Detection, Hardware/Software/Firmware Modification Detection	PI Server	Deployed in the DMZ and CRS environments, the PI Server provides the historian repository for process data through its Data Archive and generates Event Frames upon detection of abnormal manufacturing system behavior.
	Azure Defender for IoT	Passively monitors the CRS network, Testbed LAN, and DMZ for abnormal network activity via SPAN ports and is also configured to capture detailed asset information for supporting inventory and change management capabilities.
File Integrity Checking	Carbon Black	Deployed within the Testbed LAN environment with the Carbon Black agents installed on key workstations and servers to monitor the integrity of local files.
	ForceField, WORMdisk	A GreenTec fileserver is added to the DMZ environment and configured with both a ForceField and WORM drive to provide a protected archive for the historian data and the approved versions of configuration and coding files for the ICS environment.
User Authentication and Authorization	Dispel	The Dispel Wicket is deployed to the DMZ environment and integrated with the Dispel cloud-based environment to provide a virtual desktop interface (VDI) with a secure remote connection to the testbed environment. Through this connection, authorized users are permitted to access resources in both the Testbed LAN and CRS environment.
Remote Access		

873 The technology was integrated into the lab environment as shown in [Figure 4-10](#).

Figure 4-10: Build 4, CRS Complete Architecture with Security Components



874 5 Security Characteristic Analysis

875 The purpose of the security characteristic analysis is to understand the extent to which the project
876 meets its objective to demonstrate protecting information and system integrity in ICS environments. In
877 addition, it seeks to understand the security benefits and drawbacks of the example solution.

878 5.1 Assumptions and Limitations

879 The security characteristic analysis has the following limitations:

- 880 ▪ It is neither a comprehensive test of all security components nor a red-team exercise.
- 881 ▪ It cannot identify all weaknesses.
- 882 ▪ It does not include the lab infrastructure. It is assumed that devices are hardened. Testing these
883 devices would reveal only weaknesses in implementation that would not be relevant to those
884 adopting this reference architecture.

885 5.2 Example Solution Testing

886 This section presents a summary of the solution testing and results. A total of eleven tests were
887 developed for the builds. The following information is provided for each scenario:

- 888 ▪ **Objective:** Purpose of the scenario and what it will demonstrate
- 889 ▪ **Description:** Brief description of the scenario and the actions performed
- 890 ▪ **Relevant NIST Cybersecurity Framework Subcategories:** Mapping of NIST Cybersecurity
891 Framework subcategories relevant to the scenario
- 892 ▪ **Assumptions:** Assumptions about the cyber-environment
- 893 ▪ **Security Capabilities and Products:** Capabilities and products demonstrated during the scenario
- 894 ▪ **Test Procedures:** Steps performed to execute the scenario
- 895 ▪ **Expected Results:** Expected results from each capability and product demonstrated during the
896 scenario, and for each build
- 897 ▪ **Actual Test Results:** Confirm the expected results
- 898 ▪ **Overall Result:** Were the security capabilities and products able to meet the objective when the
899 scenario was executed (PASS/FAIL rating).

900 Additional information for each scenario such as screenshots captured during the execution of the test
901 procedures and detailed results from the security capabilities are presented in [Appendix D](#).

902 5.2.1 Scenario 1: Protect Host from Malware Infection via USB

Objective	This test demonstrates blocking the introduction of malware through physical access to a workstation within the manufacturing environment.
Description	An authorized user transports executable files into the manufacturing system via a USB flash drive that contains malware.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-2, DE.AE-2
Assumptions	<ul style="list-style-type: none"> ▪ User does not have administrative privileges on the target machine. ▪ User has physical access to the target machine.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting
Test Procedures	<ol style="list-style-type: none"> 1. Attempt to execute malware on the target machine.
Expected Results	<ul style="list-style-type: none"> ▪ The application allowlisting tool will detect and stop the malware upon execution.
Actual Test Results	<ul style="list-style-type: none"> ▪ The application allowlisting technology successfully blocks and alerts on the execution of the application on the workstation in all builds.
Overall Result	PASS

903 5.2.2 Scenario 2: Protect Host from Malware Infection via Network Vector

Objective	This test demonstrates the detection of malware introduced from the network.
Description	An attacker pivoting from the corporate network into the manufacturing environment attempts to insert malware to establish persistence in the manufacturing environment.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> ▪ The attacker has completed reconnaissance and initial access, gaining the ability to pivot into the manufacturing environment.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting ▪ Tenable.ot: Behavioral Anomaly Detection <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting ▪ Forescout eyeInspect: Behavioral Anomaly Detection <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting ▪ Dragos: Behavioral Anomaly Detection <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting ▪ Azure Defender for IoT: Behavioral Anomaly Detection
Test Procedures	<ol style="list-style-type: none"> 1. Attacker pivots into the manufacturing environment. 2. Attacker copies malware to the server in Testbed LAN. 3. Attacker attempts to execute malware on server in Testbed LAN.

Expected Results	<ul style="list-style-type: none"> ▪ The application allowlisting capabilities installed on target systems will block execution of the malicious code. ▪ The behavioral anomaly detection tool will capture the suspicious traffic and generate an alert.
Actual Test Results	<ul style="list-style-type: none"> ▪ The application allowlisting technology successfully blocks and alerts on the execution of the application on the workstation in all builds. ▪ The BAD tool is able to detect and alert on activity pivoting into manufacturing systems.
Overall Result	PASS

904 5.2.3 Scenario 3: Protect Host from Malware via Remote Access Connections

Objective	This test demonstrates blocking malware that is attempting to infect the manufacturing system through authorized remote access connections.
Description	A remote workstation authorized to use a remote access connection has been infected with malware. When the workstation is connected to the manufacturing environment through the remote access connection, the malware attempts to pivot and spread to vulnerable host(s).
Relevant NIST Cybersecurity Framework Subcategories	PR.AC-1, PR.AC-3, PR.AC-4, PR.AC-7, PR.MA-1, PR.MA-2, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> ▪ Infection of the remote workstation occurs prior to remote access session.

Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Cisco VPN: Remote Access ▪ ConsoleWorks: User Authentication and User Authorization <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Dispel: User Authentication and User Authorization, and Remote Access <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Cisco VPN: Remote Access ▪ ConsoleWorks: User Authentication and User Authorization <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Dispel: User Authentication and User Authorization, and Remote Access
Test Procedures	<ol style="list-style-type: none"> 1. Authorized remote user connects to the manufacturing environment. 2. Malware on remote host attempts to pivot into the manufacturing environment.
Expected Results	<ul style="list-style-type: none"> ▪ Malware will be blocked from propagation by the remote access capabilities.
Actual Test Results	<ul style="list-style-type: none"> ▪ Remote access connection blocks malware attempts to pivot into the manufacturing environment.
Overall Result	PASS

905 **5.2.4 Scenario 4: Protect Host from Unauthorized Application Installation**

Objective	This test demonstrates blocking installation and execution of unauthorized applications on a workstation in the manufacturing system.
Description	An authorized user copies downloaded software installation files from a shared network drive accessible from the workstation in the manufacturing system. The user then attempts to install the unauthorized software on the workstation.

Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> ▪ User does not have administrative privileges on the target machine. ▪ Applications to be installed are unapproved applications.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting ▪ Tenable.ot: Behavioral Anomaly Detection <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting ▪ eyeInspect: Behavioral Anomaly Detection <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Windows SRP: Application Allowlisting ▪ Dragos: Behavioral Anomaly Detection <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Carbon Black: Application Allowlisting ▪ Azure Defender for IoT: Behavioral Anomaly Detection
Test Procedures	<ol style="list-style-type: none"> 1. The user copies software to a host in the manufacturing environment. 2. The user attempts to install the software on the host. 3. The user attempts to execute software that does not require installation.
Expected Results	<ul style="list-style-type: none"> ▪ The application allowlisting tool will detect and stop the execution of the software installation or executable file. ▪ The BAD tool will capture the suspicious traffic and generate an alert.

Actual Test Results	<ul style="list-style-type: none"> ▪ The application allowlisting technology successfully blocks and alerts on the execution of the application on the workstation in all builds. ▪ The BAD tool is able to detect and alert on activity in the manufacturing system.
Overall Result	PASS

906 5.2.5 Scenario 5: Protect from Unauthorized Addition of a Device

Objective	This test demonstrates detection of an unauthorized device connecting to the manufacturing system.
Description	An individual authorized to access the physical premises connects and uses an unauthorized device on the manufacturing network.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> ▪ Ports on switch are active and available.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Tenable.ot: Behavioral Anomaly Detection <p>Build 2:</p> <ul style="list-style-type: none"> ▪ eyeInspect: Behavioral Anomaly Detection <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Dragos: Behavioral Anomaly Detection <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Azure Defender for IoT: Behavioral Anomaly Detection
Test Procedures	<ol style="list-style-type: none"> 1. The individual connects the unauthorized device to the manufacturing network. 2. The individual uses an unauthorized device to access other devices on the manufacturing network.
Expected Results	<ul style="list-style-type: none"> ▪ The behavioral anomaly detection tool will capture the suspicious traffic and generate an alert.

Actual Test Results	<ul style="list-style-type: none"> The behavioral anomaly detection tool is able to detect and alert on activity in the manufacturing system.
Overall Result	PASS

907 5.2.6 Scenario 6: Detect Unauthorized Device-to-Device Communications

Objective	This test demonstrates detection of unauthorized communications between devices.
Description	A device authorized to be on the network attempts to establish an unapproved connection.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> The environment has a predictable communications pattern.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> Tenable.ot: Behavioral Anomaly Detection. <p>Build 2:</p> <ul style="list-style-type: none"> eyeInspect: Behavioral Anomaly Detection. <p>Build 3:</p> <ul style="list-style-type: none"> Dragos: Behavioral Anomaly Detection. <p>Build 4:</p> <ul style="list-style-type: none"> Azure Defender for IoT: Behavioral Anomaly Detection.
Test Procedures	<ol style="list-style-type: none"> The device attempts to establish an unapproved connection.
Expected Results	<ul style="list-style-type: none"> The BAD tool will capture the suspicious traffic and generate an alert.
Actual Test Results	<ul style="list-style-type: none"> The BAD tool is able to detect and alert on activity in manufacturing systems.
Overall Result	PASS

908 5.2.7 Scenario 7: Protect from Unauthorized Deletion of Files

Objective	This test demonstrates protection of files from unauthorized deletion both locally and on network file share.
Description	An authorized user attempts to delete files on an engineering workstation and a shared network drive within the manufacturing system.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-1, PR.DS-6, PR.IP-4, PR.MA-1, DE.AE-2
Assumptions	<ul style="list-style-type: none"> ▪ User does not have administrative privileges on the target machine.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Carbon Black: File Integrity Checking. ▪ WORMdisk: File Integrity Protection. <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Security Onion: File Integrity Checking. ▪ WORMdisk: File Integrity Protection. <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Security Onion: File Integrity Checking. ▪ WORMdisk: File Integrity Protection. <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Carbon Black: File Integrity Checking. ▪ WORMdisk: File Integrity Protection.
Test Procedures	<ol style="list-style-type: none"> 1. User attempts to delete files located on a workstation in the manufacturing system. 2. User attempts to delete files from the network file share containing the golden images for the manufacturing system.

Expected Results	<ul style="list-style-type: none"> ▪ Deletion of files on the workstation will be detected and alerted on by the file integrity checking tool. ▪ Deletion of files on the network file share will be prevented by the file integrity checking tool.
Actual Test Results	<ul style="list-style-type: none"> ▪ Host-based file integrity checking is able to detect and alert on deletion of files. ▪ Protected network file share is able to prevent deletion of files on the network file share.
Overall Result	PASS

909 **5.2.8 Scenario 8: Detect Unauthorized Modification of PLC Logic**

Objective	This test demonstrates detection of PLC logic modification.
Description	An authorized user performs an unapproved or unauthorized modification of the PLC logic from an engineering workstation.
Relevant NIST Cybersecurity Framework Subcategories	PR.AC-3, PR.AC-7, PR.DS-6, PR.MA-1, PR.MA-2, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> • None
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Tenable.ot: Behavioral Anomaly Detection and Software Modification ▪ Cisco VPN: Remote Access ▪ ConsoleWorks: User Authentication, User Authorization, and Remote Access <p>Build 2:</p> <ul style="list-style-type: none"> ▪ eyeInspect: Behavioral Anomaly Detection and Software Modification ▪ Dispel: User Authentication and User Authorization, and Remote Access

	<p>Build 3:</p> <ul style="list-style-type: none"> ▪ Dragos: Behavioral Anomaly Detection and Software Modification ▪ Cisco VPN: Remote Access ▪ ConsoleWorks: User Authentication, User Authorization, and Remote Access <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Azure Defender for IoT: Behavioral Anomaly Detection and Software Modification ▪ Dispel: User Authentication and User Authorization, and Remote Access
Test Procedures	<ol style="list-style-type: none"> 1. The authorized user remotely connects to a manufacturing environment. 2. The user modifies and downloads a logic file to the PLC.
Expected Results	<ul style="list-style-type: none"> ▪ The behavioral anomaly detection tool will capture the suspicious traffic and generate an alert. ▪ The user authentication/authorization/remote access is able to remotely access the engineering systems as intended.
Actual Test Results	<ul style="list-style-type: none"> ▪ The behavioral anomaly detection tool is able to detect and alert on activity accessing the PLC.
Overall Result	PASS

910 **5.2.9 Scenario 9: Protect from Modification of Historian Data**

Objective	This test demonstrates blocking of modification of historian archive data.
Description	An attacker coming from the corporate network pivots into the manufacturing environment and attempts to modify historian archive data.
Relevant NIST <i>Cybersecurity Framework</i> Subcategories	PR.DS-6, PR.MA-1, DE.AE-2

Assumptions	<ul style="list-style-type: none"> ▪ The attacker has completed reconnaissance and initial access, gaining the ability to pivot into the manufacturing environment.
Security Capabilities and Products	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Tenable.ot: Behavioral Anomaly Detection. ▪ ForceField WFS: File Integrity Protection. <p>Build 2:</p> <ul style="list-style-type: none"> ▪ eyeInspect: Behavioral Anomaly Detection. ▪ ForceField WFS: File Integrity Protection. <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Dragos: Behavioral Anomaly Detection. ▪ ForceField WFS: File Integrity Protection. <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Azure Defender for IoT: Behavioral Anomaly Detection. ▪ ForceField WFS: File Integrity Protection.
Test Procedures	<ol style="list-style-type: none"> 1. Attacker pivots into the manufacturing environment from the corporate network. 2. Attacker attempts to delete historian archive data file. 3. Attacker attempts to replace historian archive data file.
Expected Results	<ul style="list-style-type: none"> ▪ The file operations will be blocked by the file integrity checking tool.
Actual Test Results	<ul style="list-style-type: none"> ▪ File integrity checking tool is able to prevent file operations on the protected files.
Overall Result	PASS

911 5.2.10 Scenario 10: Detect Sensor Data Manipulation

Objective	This test demonstrates detection of atypical data reported to the historian.
Description	A sensor in the manufacturing system begins sending atypical data values to the historian.
Relevant NIST Cybersecurity Framework Subcategories	PR.IP-4, PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> Devices in the manufacturing system (HMI and PLCs) are not validating sensor data.
Security Capabilities and Products	<ul style="list-style-type: none"> PI Server: Behavioral Anomaly Detection
Test Procedures	1. A sensor sends invalid data to the historian.
Expected Results	<ul style="list-style-type: none"> The behavioral anomaly detection capability will detect atypical sensor data and generate alerts.
Actual Test Results	<ul style="list-style-type: none"> The behavioral anomaly detection tool is able to detect atypical data and create an event frame.
Overall Result	PASS

912 5.2.11 Scenario 11: Detect Unauthorized Firmware Modification

Objective	This test demonstrates detection of device firmware modification.
Description	An authorized user performs a change of the firmware on a PLC.
Relevant NIST Cybersecurity Framework Subcategories	PR.DS-6, PR.MA-1, DE.AE-1, DE.AE-2, DE.AE-3, DE.CM-1, DE.CM-3, DE.CM-7
Assumptions	<ul style="list-style-type: none"> None

<p>Security Capabilities and Products</p>	<p>Build 1:</p> <ul style="list-style-type: none"> ▪ Cisco VPN: Remote Access. ▪ ConsoleWorks: Remote Access, User Authentication, and User Authorization. ▪ Tenable.ot: Behavioral Anomaly Detection and Firmware Modification. <p>Build 2:</p> <ul style="list-style-type: none"> ▪ Dispel: Remote Access, User Authentication, and User Authorization. ▪ eyeInspect and ICSPatrol: Behavioral Anomaly Detection and Firmware Modification. <p>Build 3:</p> <ul style="list-style-type: none"> ▪ Cisco VPN: Remote Access. ▪ ConsoleWorks: Remote Access, User Authentication, and User Authorization. ▪ Dragos: Behavioral Anomaly Detection and Firmware Modification. <p>Build 4:</p> <ul style="list-style-type: none"> ▪ Dispel: Remote Access, User Authentication, and User Authorization. ▪ Azure Defender for IoT: Behavioral Anomaly Detection and Firmware Modification.
<p>Test Procedures</p>	<ol style="list-style-type: none"> 1. Authorized remote user connects to manufacturing environment. 2. The user changes firmware on the PLC component.
<p>Expected Results</p>	<ul style="list-style-type: none"> ▪ The behavioral anomaly detection tool will identify the change to the PLC and generate an alert for review.
<p>Actual Test Results</p>	<ul style="list-style-type: none"> ▪ The behavioral anomaly tool is able to detect and generate alerts for updates to PLC component firmware.
<p>Overall Result</p>	<p>PASS</p>

913 5.3 Scenarios and Findings

914 One aspect of our security evaluation involved assessing how well the reference design addresses the
915 security characteristics that it was intended to support. The NIST *Cybersecurity Framework*
916 Subcategories were used to provide structure to the security assessment by consulting the specific
917 sections of each standard that are cited in reference to a Subcategory. The cited sections provide
918 validation points that the example solution would be expected to exhibit. Using the NIST *Cybersecurity*
919 *Framework* Subcategories as a basis for organizing our analysis allowed us to systematically consider
920 how well the reference design supports the intended security characteristics.

921 5.3.1 PR.AC-1: Identities and credentials are issued, managed, verified, revoked, 922 and audited for authorized devices, users, and processes

923 This NIST *Cybersecurity Framework* Subcategory is supported through the user authentication and user
924 authorization capabilities in addition to the native credential management capabilities associated with
925 the tools. In each of the systems, user accounts were issued, managed, verified, revoked, and audited.

926 5.3.2 PR.AC-3: Remote access is managed

927 This NIST *Cybersecurity Framework* Subcategory is supported by remote access tools integrated with the
928 user authentication and authorization systems. Together, these tools provide a secure channel for an
929 authorized user to access the manufacturing environment from a remote location. These tools are
930 configurable to allow organizations to control who can remotely access the system, what the user can
931 access, and when access is allowed by a user.

932 5.3.3 PR.AC-4: Access permissions and authorizations are managed, 933 incorporating the principles of least privilege and separation of duties

934 This NIST *Cybersecurity Framework* Subcategory is supported by the user authentication and user
935 authorization capabilities. These tools are used to grant access rights to each user and notify if
936 suspicious activity is detected. This includes granting access to maintenance personnel responsible for
937 certain sub-systems or components of the ICS environments while preventing them from accessing
938 other sub-systems or components. Suspicious activities include operations attempted by an
939 unauthorized user, restricted operations performed by an authenticated user who is not authorized to
940 perform the operations, and operations that are performed outside of the designated time frame.

941 5.3.4 PR.AC-7: Users, devices, and other assets are authenticated (e.g., single-
942 factor, multi-factor) commensurate with the risk of the transaction (e.g.,
943 individuals' security and privacy risks and other organizational risks)

944 This NIST *Cybersecurity Framework* Subcategory is supported through the user authentication and user
945 authorization capabilities in addition to the native credential management capabilities associated with
946 the tools. Based on the risk assessment of the lab, the authentication and authorization systems used
947 user passwords as one factor to verify identity and grant access to the environment. To bolster security
948 in the environment, IP addresses were used as a secondary factor to for remote access.

949 5.3.5 PR.DS-1: Data-at-rest is protected

950 This NIST *Cybersecurity Framework* Subcategory is supported using file integrity checking. For end
951 points, the file integrity tools alert when changes to local files are detected. For historian backups and
952 system program and configuration backups, data was stored on read only or write-once drives to
953 prevent data manipulation.

954 5.3.6 PR.DS-6: Integrity checking mechanisms are used to verify software,
955 firmware, and information integrity

956 This NIST *Cybersecurity Framework* Subcategory is supported through file integrity checking tools and
957 the behavioral anomaly detection tools. The file integrity checking tools monitor the information on the
958 manufacturing end points for changes. The behavioral anomaly detection tools monitor the
959 environments for changes made to software, firmware, and validate sensor and actuator information.

960 5.3.7 PR.IP-4: Backups of information are conducted, maintained, and tested

961 This NIST *Cybersecurity Framework* Subcategory is supported by file integrity checking using secure
962 storage to protect backup data. System configuration settings, PLC logic files, and historian databases all
963 have backups stored on secure storage disks. The secure storage is constructed in a way that prohibits
964 modifying or deleting data that is on the disk.

965 5.3.8 PR.MA-1: Maintenance and repair of organizational assets are performed
966 and logged, with approved and controlled tools

967 This NIST *Cybersecurity Framework* Subcategory is supported by a combination of tools including
968 application allowlisting, the user authentication and user authorization tools, and the behavior anomaly
969 detection tools. User authentication and user authorization tools provide a controlled environment for
970 authorized users to interact with the manufacturing environment. Behavior anomaly detection tools
971 provide a means to detect maintenance activities in the environment such as PLC logic modification or

972 PLC firmware updates via the network. This information can be combined with data from a
973 computerized maintenance management system to ensure that all maintenance activities are
974 appropriately approved and logged. Also, application allowlisting prevents unapproved software from
975 running on systems to ensure that only approved tools are used for maintenance activities.

976 5.3.9 PR.MA-2: Remote maintenance of organizational assets is approved, 977 logged, and performed in a manner that prevents unauthorized access

978 This NIST *Cybersecurity Framework* Subcategory is supported by the remote access capability integrated
979 with the user authentication and user authorization system. The tools in the solution were used to grant
980 access for performing remote maintenance on specific assets. The tools prevent unauthorized users
981 from gaining access to the manufacturing environment.

982 5.3.10 DE.AE-1: A baseline of network operations and expected data flows for 983 users and systems is established and managed

984 This NIST *Cybersecurity Framework* Subcategory is supported by behavior anomaly detection tools.
985 Network baselines were established and approved based on an understanding of normal operations and
986 data flows identified by the behavior anomaly detection tools.

987 5.3.11 DE.AE-2: Detected events are analyzed to understand attack targets and 988 methods

989 This NIST *Cybersecurity Framework* Subcategory is supported by all the capabilities included in the
990 solutions. Logs of suspicious activities from the tools can be used by security managers and engineers to
991 understand what unusual activity has occurred in the manufacturing system. Analyzing these logs
992 provides a mechanism to determine what systems were accessed and what actions may have been
993 performed on them. Although not demonstrated in these solutions, an analytic engine would enhance
994 the detection capability of the solution.

995 5.3.12 DE.AE-3: Event data are collected and correlated from multiple sources and 996 sensors

997 This NIST *Cybersecurity Framework* Subcategory is supported by all the capabilities included in the
998 solutions. Each tool detects different aspects of the scenarios from diverse perspectives. Although not
999 demonstrated in these solutions, a data aggregation and correlation tool such as a security information
1000 and event management (SIEM) tool would enhance the detection capability of the solution.

1001 **5.3.13 DE.CM-1: The network is monitored to detect potential cybersecurity**
1002 **events**

1003 This NIST *Cybersecurity Framework* Subcategory is supported by the behavioral anomaly detection and
1004 remote access capabilities used in the example solutions to monitor the manufacturing network to
1005 detect potential cybersecurity events. The behavioral anomaly detection tools monitor network
1006 communications at the external boundary of the system and at key internal points within the network,
1007 along with user activities and traffic patterns, and compare it to the established baseline. The remote
1008 access capabilities monitor the network communications at the external boundary of the system. This
1009 helps detect unauthorized local, network, and remote connections and identify unauthorized use of the
1010 manufacturing system.

1011 **5.3.14 DE.CM-3: Personnel activity is monitored to detect potential cybersecurity**
1012 **events**

1013 This NIST *Cybersecurity Framework* Subcategory is supported by the authentication and authorization
1014 tools that allow for monitoring personnel activity while connected through these tools. Further,
1015 application allowlisting and file integrity checking tools provide the ability to monitor user actions on
1016 hosts. Additionally, behavioral anomaly detection tools monitor and record events associated with
1017 personnel actions traversing network traffic. Each tool provides a different perspective in monitoring
1018 personnel activity within the environment. The resulting alerts and logs from these tools can be
1019 monitored individually or collectively to support investigations for potential malicious or unauthorized
1020 activity within the environment.

1021 **5.3.15 DE.CM-7: Monitoring for unauthorized personnel, connections, devices,**
1022 **and software is performed**

1023 This NIST *Cybersecurity Framework* Subcategory is supported by behavioral anomaly detection,
1024 application allowlisting, user authentication and user authorization, and remote access capabilities of
1025 the solutions. The behavioral anomaly detection tools established a baseline of information for
1026 approved assets and connections. Then the manufacturing network is monitored using the behavioral
1027 anomaly detection capability for any deviation by the assets and connections from the established
1028 baseline. If any deviation is detected, an alert is generated. Additionally, the application allowlisting tool
1029 blocks any unauthorized application installation or execution and generates an alert on these events.
1030 User authentication and user authorization tools monitor for unauthorized personnel connecting to the
1031 environment. Remote access capabilities monitor for unauthorized connections to the environment.

1032 **6 Future Build Considerations**

1033 This guide has presented technical solutions for maintaining and monitoring system and information
1034 integrity, which will help detect and prevent incidents in a manufacturing environment. Future builds
1035 should demonstrate methods and techniques for fusing event and log data from multiple platforms into
1036 a security operations center (SOC) to improve monitoring and detection capabilities for an organization.
1037 Future builds should also demonstrate how to recover from a loss of system or information integrity
1038 such as a ransomware attack for ICS environments.

1039 Additionally, trends in manufacturing such as Industry 4.0 and the industrial IoT are increasing
1040 connectivity, increasing the attack surface, and increasing the potential for vulnerabilities. Future builds
1041 should consider how these advances can be securely integrated into manufacturing environments.

1042	Appendix A	List of Acronyms
1043	AAL	Application Allowlisting
1044	AD	Active Directory
1045	BAD	Behavioral Anomaly Detection
1046	CRS	Collaborative Robotic System
1047	CRADA	Cooperative Research and Development Agreement
1048	CSF	NIST Cybersecurity Framework
1049	CSMS	Cybersecurity for Smart Manufacturing Systems
1050	DMZ	Demilitarized Zone
1051	EL	Engineering Laboratory
1052	FOIA	Freedom of Information Act
1053	ICS	Industrial Control System
1054	IoT	Internet of Things
1055	IT	Information Technology
1056	KSA	Knowledge, Skills and Abilities
1057	LAN	Local Area Network
1058	NCCoE	National Cybersecurity Center of Excellence
1059	NFS	Network File Share
1060	NIST	National Institute of Standards and Technology
1061	NISTIR	NIST Interagency or Internal Report
1062	NTP	Network Time Protocol
1063	OT	Operational Technology
1064	PCS	Process Control System
1065	PLC	Programmable Logic Controller
1066	SCADA	Supervisory Control and Data Acquisition

1067	SIEM	Security Information and Event Management
1068	SMB	Server Message Block
1069	SOC	Security Operations Center
1070	SP	Special Publication
1071	SRP	Software Restriction Policies
1072	SSH	secure shell
1073	VDI	Virtual Desktop Interface
1074	VLAN	Virtual Local Area Network
1075	VPN	Virtual Private Network

Appendix B Glossary

Access Control	<p>The process of granting or denying specific requests to: 1) obtain and use information and related information processing services; and 2) enter specific physical facilities (e.g., federal buildings, military establishments, border crossing entrances).</p> <p>SOURCE: Federal Information Processing Standard (FIPS) 201; CNSSI-4009</p>
Architecture	<p>A highly structured specification of an acceptable approach within a framework for solving a specific problem. An architecture contains descriptions of all the components of a selected, acceptable solution while allowing certain details of specific components to be variable to satisfy related constraints (e.g., costs, local environment, user acceptability).</p> <p>SOURCE: FIPS 201-2</p>
Authentication	<p>Verifying the identity of a user, process, or device, often as a prerequisite to allowing access to resources in an information system.</p> <p>SOURCE: FIPS 200</p>
Authorization	<p>The right or a permission that is granted to a system entity to access a system resource.</p> <p>SOURCE: NIST SP 800-82 Rev. 2</p>
Backup	<p>A copy of files and programs made to facilitate recovery if necessary.</p> <p>SOURCE: NIST SP 800-34 Rev. 1</p>
Continuous Monitoring	<p>Maintaining ongoing awareness to support organizational risk decisions.</p> <p>SOURCE: NIST SP 800-137</p>
CRADA	<p>Collaborative Research and Development Agreement</p> <p>SOURCE: NIST SP 1800-5b, NIST SP 1800-5c</p>

Cybersecurity	<p>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.</p> <p>SOURCE: CNSSI 4009-2015 (NSPD-54/HSPD-23)</p>
Cyber Attack	<p>An attack, via cyberspace, targeting an enterprise's use of cyberspace for the purpose of disrupting, disabling, destroying, or maliciously controlling a computing environment/infrastructure; or destroying the integrity of the data or stealing controlled information.</p> <p>SOURCE: NIST SP 800-30 Rev. 1</p>
Data	<p>A subset of information in an electronic format that allows it to be retrieved or transmitted.</p> <p>SOURCE: CNSSI-4009</p>
Data Integrity	<p>The property that data has not been changed, destroyed, or lost in an unauthorized or accidental manner.</p> <p>SOURCE: CNSSI-4009</p>
File Integrity Checking	<p>Software that generates, stores, and compares message digests for files to detect changes made to the files.</p> <p>SOURCE: NIST SP 800-115</p>
Firmware	<p>Computer programs and data stored in hardware – typically in read-only memory (ROM) or programmable read-only memory (PROM) – such that the programs and data cannot be dynamically written or modified during execution of the programs.</p> <p>SOURCE: CNSSI 4009-2015</p>
Industrial Control Systems	<p>An information system used to control industrial processes such as manufacturing, product handling, production, and distribution.</p> <p>SOURCE: NIST SP 800-30 Rev. 1</p>

Information Security	<p>The protection of information and information systems from unauthorized access, use, disclosure, disruption, modification, or destruction in order to provide confidentiality, integrity, and availability.</p> <p>SOURCE: FIPS 199 (44 U.S.C., Sec. 3542)</p>
Information System	<p>A discrete set of information resources organized for the collection, processing, maintenance, use, sharing, dissemination, or disposition of information.</p> <p>SOURCE: FIPS 200 (44 U.S.C., Sec. 3502)</p>
Information Technology	<p>Any equipment or interconnected system or subsystem of equipment that is used in the automatic acquisition, storage, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of data or information by the executive agency.</p> <p>SOURCE: FIPS 200</p>
Log	<p>A record of the events occurring within an organization's systems and networks.</p> <p>SOURCE: NIST SP 800-92</p>
Malware	<p>A program that is inserted into a system, usually covertly, with the intent of compromising the confidentiality, integrity, or availability of the victim's data, applications, or operating system.</p> <p>SOURCE: NIST SP 800-111</p>
Network Traffic	<p>Computer network communications that are carried over wired or wireless networks between hosts.</p> <p>SOURCE: NIST SP 800-86</p>
Operational Technology	<p>Programmable systems or devices that interact with the physical environment (or manage devices that interact with the physical environment).</p> <p>SOURCE: NIST SP 800-37 Rev. 2</p>
Privacy	<p>Assurance that the confidentiality of, and access to, certain information about an entity is protected.</p> <p>SOURCE: NIST SP 800-130</p>

Remote Access	<p>Access to an organizational information system by a user (or an information system) communicating through an external, non-organization-controlled network (e.g., the Internet).</p> <p>SOURCE: NIST SP 800-128 under Remote Access from NIST SP 800-53</p>
Risk	<p>The level of impact on organizational operations (including mission, functions, image, or reputation), organizational assets, or individuals resulting from the operation of an information system given the potential impact of a threat and the likelihood of that threat occurring.</p> <p>SOURCE: FIPS 200</p>
Risk Assessment	<p>The process of identifying the risks to system security and determining the probability of occurrence, the resulting impact, and additional safeguards that would mitigate this impact. Part of Risk Management and synonymous with Risk Analysis.</p> <p>SOURCE: NIST SP 800-63-2</p>
Risk Management Framework	<p>The Risk Management Framework (RMF), presented in NIST SP 800-37, provides a disciplined and structured process that integrates information security and risk management activities into the system development life cycle.</p> <p>SOURCE: NIST SP 800-82 Rev. 2 (NIST SP 800-37)</p>
Security Control	<p>A protection measure for a system</p> <p>SOURCE: NIST SP 800-123</p>
Virtual Machine	<p>Software that allows a single host to run one or more guest operating systems</p> <p>SOURCE: NIST SP 800-115</p>

1077 Appendix C References

- 1078 [1] C. Singleton et al., X-Force Threat Intelligence Index 2021, IBM, February 2021,
1079 <https://www.ibm.com/security/data-breach/threat-intelligence>
- 1080 [2] A Sedgewick et al., *Guide to Application Whitelisting*, NIST SP 800-167, NIST, Oct. 2015.
1081 Available: <http://dx.doi.org/10.6028/NIST.SP.800-167>.
- 1082 [3] Department of Homeland Security, Critical Manufacturing Sector Cybersecurity Framework
1083 Implementation Guidance, 2015. Available:
1084 [https://www.cisa.gov/sites/default/files/publications/critical-manufacturingcybersecurity-
framework-implementation-guide-2015-508.pdf](https://www.cisa.gov/sites/default/files/publications/critical-manufacturingcybersecurity-
1085 framework-implementation-guide-2015-508.pdf).
- 1086 [4] Executive Order no. 13636, *Improving Critical Infrastructure Cybersecurity*, DCPD201300091,
1087 Feb. 12, 2013. Available: [https://obamawhitehouse.archives.gov/the-press-
office/2013/02/12/executive-order-improving-critical-infrastructure-cybersecurity](https://obamawhitehouse.archives.gov/the-press-
1088 office/2013/02/12/executive-order-improving-critical-infrastructure-cybersecurity).
- 1089 [5] NIST, *Framework for Improving Critical Infrastructure Cybersecurity*, V1.1 April 16, 2018.
1090 Available: <https://doi.org/10.6028/NIST.CSWP.04162018>.
- 1091 [6] J. McCarthy et al., Securing Manufacturing Industrial Control Systems: Behavioral Anomaly
1092 Detection, NIST Interagency Report (NISTIR) 8219, NIST, Nov. 2018. Available:
1093 <https://www.nccoe.nist.gov/sites/default/files/library/mf-ics-nistir-8219.pdf>.
- 1094 [7] K. Stouffer et al., Cybersecurity Framework Manufacturing Profile, NIST Internal Report 8183,
1095 NIST, May 2017. Available: <https://nvlpubs.nist.gov/nistpubs/ir/2017/NIST.IR.8183.pdf>.
- 1096 [8] R. Candell et al., An Industrial Control System Cybersecurity Performance Testbed, NISTIR 8089,
1097 NIST, Nov. 2015. Available: <http://nvlpubs.nist.gov/nistpubs/ir/2015/NIST.IR.8089.pdf>.
- 1098 [9] Security and Privacy Controls for Federal Information Systems and Organizations, NIST SP 800-53
1099 Revision 5, NIST, Apr. 2013. Available: <https://doi.org/10.6028/NIST.SP.800-53r5>.
- 1100 [10] W. Newhouse et al., National Initiative for Cybersecurity Education (NICE) Cybersecurity
1101 Workforce Framework, NIST SP 800-181, Aug. 2017. Available:
1102 <http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-181.pdf>.
- 1103 [11] J. Cawthra et al., Data Integrity: Identifying and Protecting Assets Against Ransomware and
1104 Other Destructive Events, NIST Special Publication 1800-25 Dec. 2020,
1105 <https://doi.org/10.6028/NIST.SP.1800-25>.
- 1106 [12] Celia Paulsen, Robert Byers, Glossary of Key Information Security Terms NISTIR 7298,
1107 <https://nvlpubs.nist.gov/nistpubs/ir/2019/NIST.IR.7298r3.pdf>.

- 1108 [13] U.S.-Canada Power Systems Outage Task Force, Final Report on the August 14, 2003 Blackout in
1109 the United States and Canada: Causes and Recommendations. Available:
1110 [https://www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/Outage_Task_Force
-_DRAFT_Report_on_Implementation.pdf](https://www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/Outage_Task_Force
1111 -_DRAFT_Report_on_Implementation.pdf)
- 1112 [14] K. Stouffer et al., Guide to Industrial Control Systems (ICS) Security, NIST SP 800-82 Revision 2,
1113 NIST, June 2015, Available: [https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-
82r2.pdf](https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-
1114 82r2.pdf)
- 1115 [15] J. J. Downs and E. F. Vogel, "A Plant-wide Industrial Problem Process," *Comput. Chem. Eng.*, vol.
1116 17, no. 3, 1993, pp. 245–255.

DRAFT

1117 **Appendix D Scenario Execution Results**

1118 The following section provides details regarding the execution and results from each scenario. Details
1119 such as usernames, filenames, IP addresses, etc. are specific to the NCCoE lab environment and are
1120 provided for reference only.

1121 **D.1 Executing Scenario 1: Protect Host from Malware via USB**

1122 An authorized user inserts a USB storage device containing a malware file (*1.exe*) into a system in the
1123 manufacturing environment (e.g., an engineering workstation). After insertion, the malware file (*1.exe*)
1124 attempts to execute. The expected outcome is that the application allowlisting technology blocks the
1125 execution of the file.

1126 **D.1.1 Build 1**

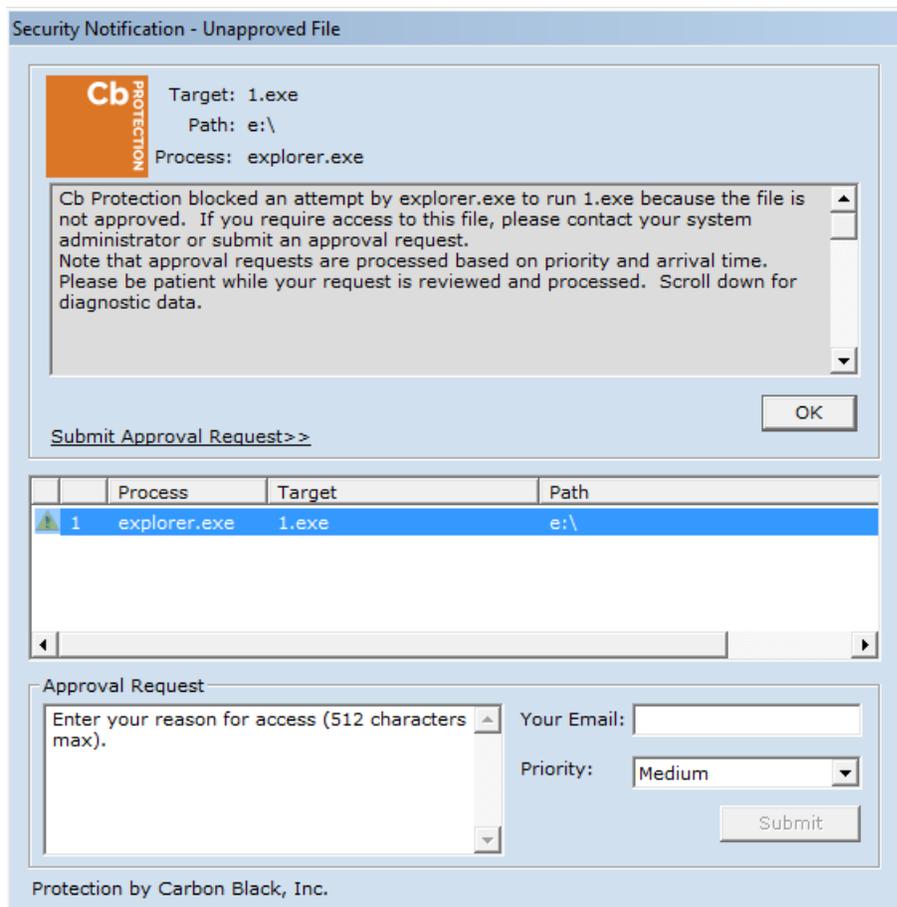
1127 *D.1.1.1 Configuration*

- 1128 ▪ Application Allowlisting: Carbon Black
- 1129 • Agent installed on an HMI Workstation and configured to communicate to the Carbon
1130 Black Server.

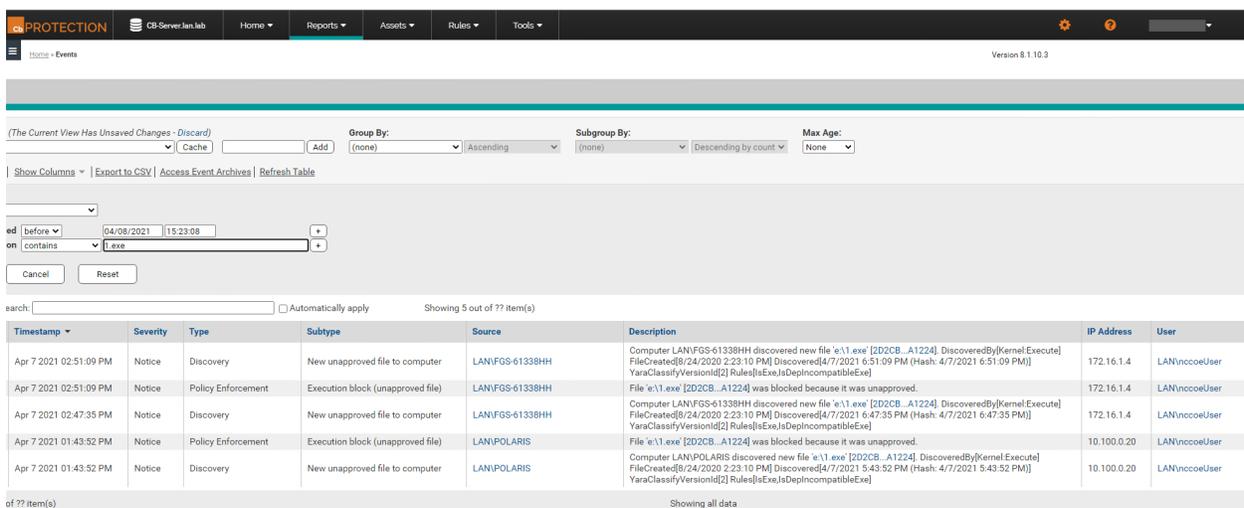
1131 *D.1.1.2 Test Results*

1132 Carbon Black successfully detects and blocks the malware (*1.exe*) from running as shown in [Figure D-1](#).
1133 [Figure D-2](#) shows Carbon Black's server log. The log provides more detail on the activity detected by
1134 Carbon Black.

1135 Figure D-1: An Alert from Carbon Black Showing that Malware (1.exe) was Blocked from Executing



1136 Figure D-2: Carbon Black's Server Provides Additional Details and Logs of the Event



DRAFT

1137 **Figure D-3: Carbon Black's Server Log of the Event**

```
File 'e:\1.exe' [2D2CB...A1224] was blocked because it was unapproved.  
Computer LAN\POLARIS discovered new file 'e:\1.exe' [2D2CB...A1224]. DiscoveredBy[Kernel:Execute]  
FileCreated[8/24/2020 2:23:10 PM] Discovered[4/7/2021 5:43:52 PM (Hash: 4/7/2021 5:43:52 PM)]  
YaraClassifyVersionId[2] Rules[IsExe,IsDepIncompatibleExe]
```

1138 **D.1.2 Build 2**

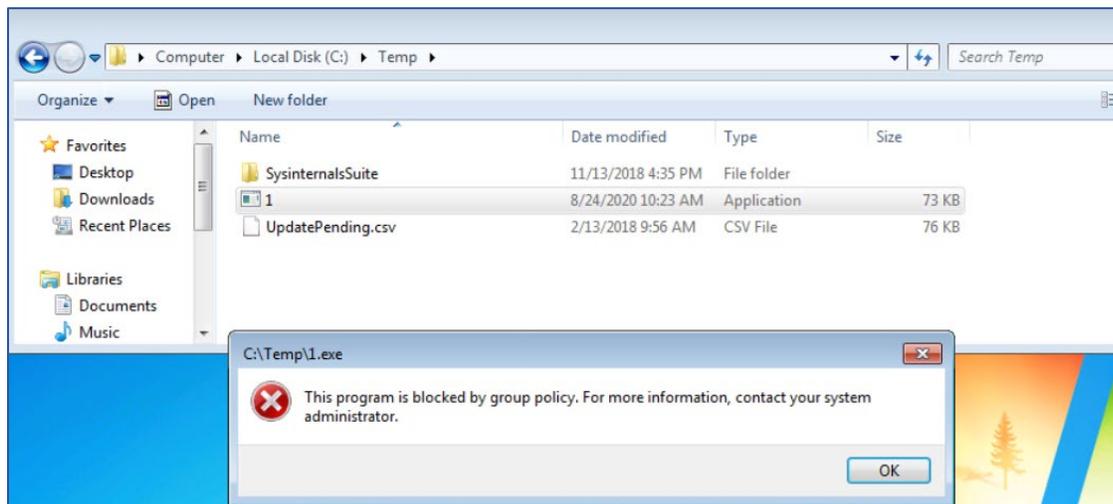
1139 *D.1.2.1 Configuration*

- 1140 ▪ Application Allowlisting: windows SRP
- 1141 • Allowlisting policies are applied to HMI Workstation.

1142 *D.1.2.2 Test Results*

1143 The execution of *1.exe* is blocked successfully when Windows SRP is enforced as shown in Figure D-4.

1144 **Figure D-4: Windows 7 Alert as a Result of Windows SRP Blocking the Execution of 1.exe**



1145 **D.1.3 Build 3**

1146 *D.1.3.1 Configuration*

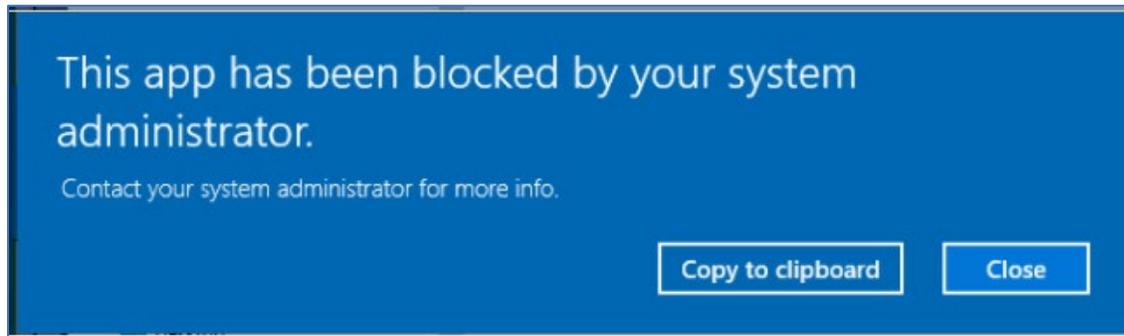
- 1147 ▪ Application Allowlisting: Windows SRP
- 1148 • Allowlisting policies are applied to Engineering Workstation.

1149 *D.1.3.2 Test Results*

1150 For Build 3, Windows SRP application allowlisting is enabled in the Collaborative Robotics environment.

1151 [Figure D-5](#) shows that the executable is blocked on the CRS workstation.

1152 **Figure D-5: Windows 10 Alert as a Result of Windows SRP Blocking the Execution of 1.exe**



1153 **D.1.4 Build 4**

1154 *D.1.4.1 Configuration*

1155 ▪ Application Allowlisting : Carbon Black

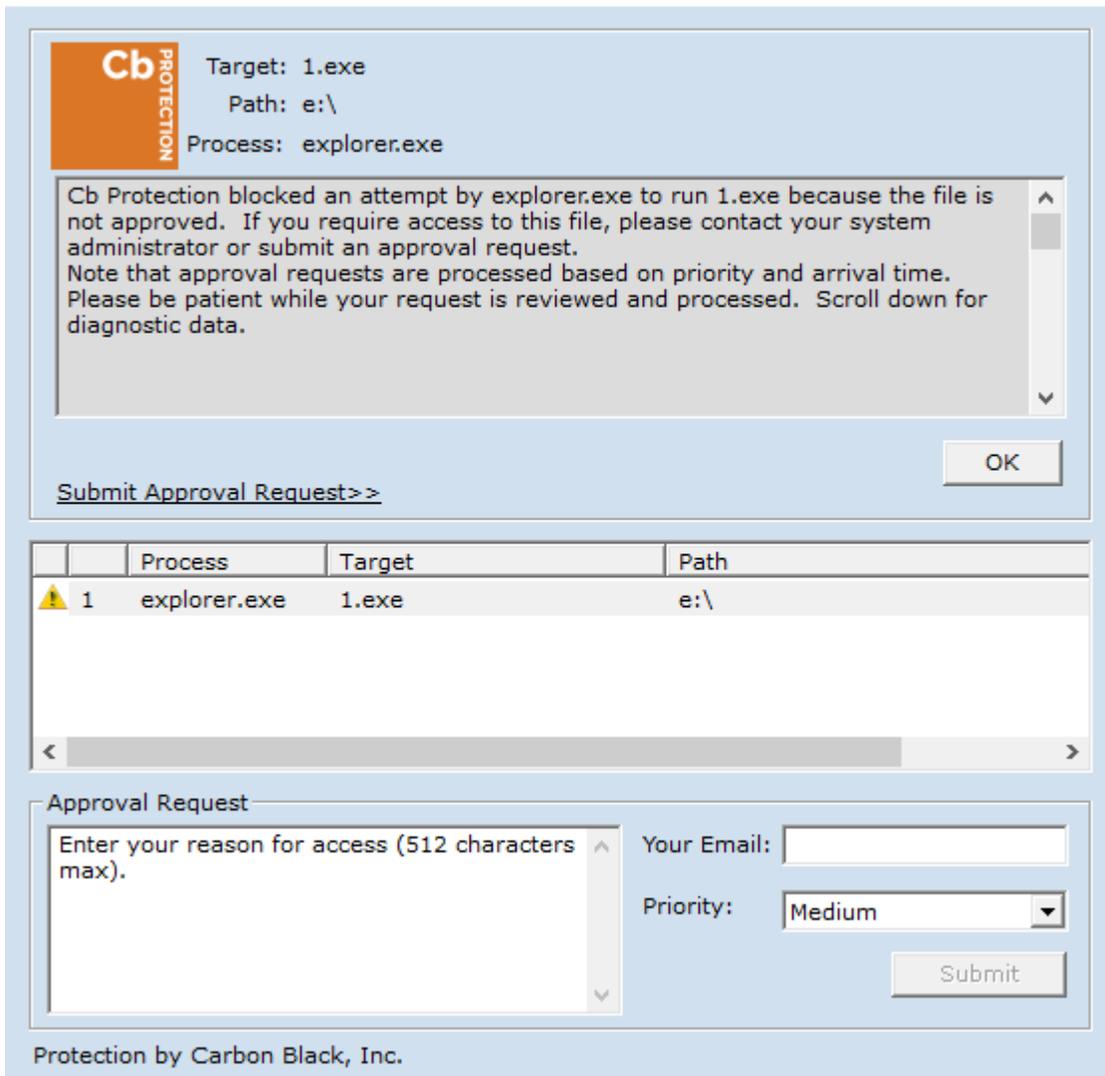
- 1156 • Agent installed on Engineering Workstation and configured to communicate to the Carbon
- 1157 Black Server.

1158 *D.1.4.2 Test Results*

1159 Carbon Black successfully detects and blocks the malicious file as shown by the Carbon Black notification
1160 in [Figure D-6](#).

1161 **Figure D-6: Carbon Black Blocks the Execution of 1.exe for Build 4**

Security Notification - Unapproved File

1162 **D.2 Executing Scenario 2: Protect Host from Malware via Network Vector**

1163 An attacker who has already gained access to the corporate network attempts to pivot into the ICS
 1164 environment through the DMZ. From a system in the DMZ, the attacker scans for vulnerable systems in
 1165 the Testbed LAN environment to continue pivoting toward the ICS environments. In an attempt to
 1166 establish a persistent connection into the ICS environment, the malicious file (1.exe) is copied to a
 1167 system in the Testbed LAN environment and executed. The expected outcome is that the malicious file is
 1168 blocked by the application allowlisting tool, and the RDP and scanning network activity is observed by
 1169 the behavioral anomaly detection tool.

1170 **D.2.1 Build 1**

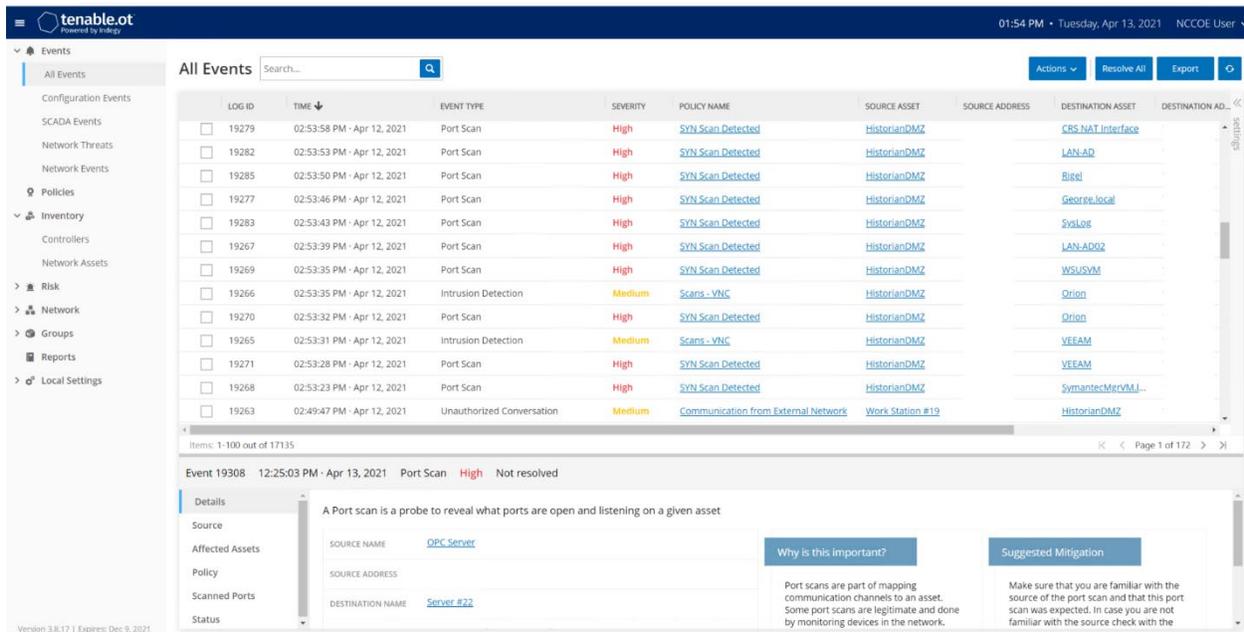
1171 **D.2.1.1 Configuration**

- 1172 ▪ Application Allowlisting: Carbon Black
 - 1173 • Agent installed on systems in the DMZ, Testbed LAN, and PCS VLAN 1 and 2 and configured to communicate to the Carbon Black Server.
- 1175 ▪ Behavior Anomaly Detection: Tenable.ot
 - 1176 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

1177 **D.2.1.2 Test Results**

1178 Abnormal network traffic is detected by Tenable.ot as shown in Figure D-7. [Figure D-8](#) shows the initial
 1179 RDP connection between an external system and the DMZ system, and [Figure D-9](#) provides more detail
 1180 of the session activity. [Figure D-10](#) show that Tenable.ot detected VNC connection between the DMZ
 1181 and the Testbed LAN. [Figure D-11](#) shows a detected ports scan performed by the DMZ system target at a
 1182 system in the Testbed LAN. Tenable.ot detected the RDP scan from the DMZ to the NESSUS VM in the
 1183 Testbed LAN, as shown in [Figure D-12](#), and [Figure D-13](#) provides more details on that detected event.
 1184 The execution of the malware (1.exe) is blocked by Carbon Black agent as shown in [Figure D-14](#).

1185 **Figure D-7: Tenable.ot Dashboard Showing the Events that were Detected**



1186 Figure D-8: Detected RDP Session Activity from External System to DMZ System

LOG ID	TIME ↓	EVENT TYPE	SEVERITY	POLICY NAME	SOURCE ASSET	SOURCE ADDRESS	DESTINATION ASSET	DESTINATION AD...
<input type="checkbox"/> 19251	02:18:57 PM - Apr 12, 2021	Unauthorized Conversation	Medium	Communication from External Network	Work Station #19		HistorianDMZ	
<input type="checkbox"/> 19250	02:18:45 PM - Apr 12, 2021	Unauthorized Conversation	Medium	Communication from External Network	Work Station #19		HistorianDMZ	

1187 Figure D-9: Event Detection Detail for the RDP Connection from the External System to the Historian in
1188 the DMZ

Event 19251 02:18:57 PM · Apr 12, 2021 Unauthorized Conversation **Medium** Not resolved

Details

A conversation in an unauthorized protocol has been detected

SOURCE NAME	Work Station #19
SOURCE ADDRESS	
DESTINATION NAME	HistorianDMZ
DESTINATION ADDRESS	
PROTOCOL	RDP (tcp/3389)
PORT	3389
PROTOCOL GROUP	In Any Protocol

1189 Figure D-10: Tenable.ot Detected VNC Connection Between the DMZ and the Testbed LAN

Event 19273 02:54:32 PM · Apr 12, 2021 Intrusion Detection **Medium** Not resolved

Details

Intrusion Detection events may indicate malicious communications based on known traffic patterns

SOURCE NAME	HistorianDMZ
SOURCE ADDRESS	10.100.1.4
DESTINATION NAME	Stratix8300 FA2
DESTINATION ADDRESS	10.100.0.40 172.16.2.1
PROTOCOL	rfb (tcp/5900)
PORT	5900
RULE MESSAGE	ET SCAN Potential VNC Scan 5900-5920
SID	2002911

Why is this important?

Intrusion detection events may indicate that the network has been compromised and is exposed to malicious entities. It is important to be aware of any such traffic that may indicate reconnaissance activity, attacks on the network or propagation of a threat to/from other subnets of the network.

Suggested Mitigation

Make sure that the source and destination assets are familiar to you. In addition, depending on the suspicious traffic, you may consider updating anti-virus definitions, firewall rules or other security patches. You can open the Rule Details panel to view additional details about this particular rule.

1190 **Figure D-11: Tenable.ot Event Detail for a Detected Port Scan from a DMZ System Targeting a System in**
 1191 **the Testbed LAN**

Event 19288 02:55:24 PM · Apr 12, 2021 Port Scan **High** Not resolved

<p>Details</p> <p>Source</p> <p>Affected Assets</p> <p>Policy</p> <p>Scanned Ports</p> <p>Status</p>	<p>A Port scan is a probe to reveal what ports are open and listening on a given asset</p> <table border="1"> <tr> <td>SOURCE NAME</td> <td>HistorianDMZ</td> </tr> <tr> <td>SOURCE ADDRESS</td> <td>10.100.1.4</td> </tr> <tr> <td>DESTINATION NAME</td> <td>Lantron</td> </tr> <tr> <td>DESTINATION ADDRESS</td> <td>10.100.0.101 192.168.0.205</td> </tr> <tr> <td>PROTOCOL</td> <td>tcp</td> </tr> <tr> <td>PORT</td> <td></td> </tr> </table>	SOURCE NAME	HistorianDMZ	SOURCE ADDRESS	10.100.1.4	DESTINATION NAME	Lantron	DESTINATION ADDRESS	10.100.0.101 192.168.0.205	PROTOCOL	tcp	PORT		<p>Why is this important?</p> <p>Port scans are part of mapping communication channels to an asset. Some port scans are legitimate and done by monitoring devices in the network. However, such mapping may also be done in the early stages of an attack, in order to detect vulnerable and accessible ports for malicious communication.</p>	<p>Suggested Mitigation</p> <p>Make sure that you are familiar with the source of the port scan and that this port scan was expected. In case you are not familiar with the source check with the source asset owner to see whether this was a planned and expected port scan. If not, check which other assets have been scanned by the source asset and consider isolating the source asset to decrease network exposure while you investigate further.</p>
SOURCE NAME	HistorianDMZ														
SOURCE ADDRESS	10.100.1.4														
DESTINATION NAME	Lantron														
DESTINATION ADDRESS	10.100.0.101 192.168.0.205														
PROTOCOL	tcp														
PORT															

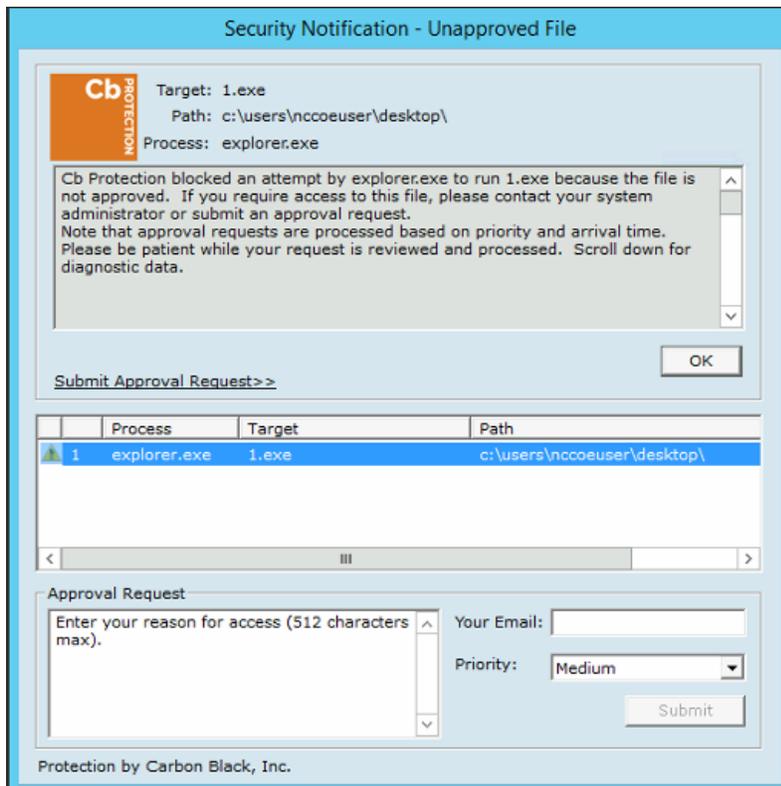
1192 **Figure D-12: Detected RDP from a DMZ system to a Testbed LAN system**

19299 03:01:39 PM · Apr 12, 2021 RDP Connection (Authenticated) **Medium** External RDP Communication HistorianDMZ 10.100.1.4 NESSUSVM 10.100.0.25

1193 **Figure D-13: Tenable.ot Event Detail Showing the RDP Connection Between the Historian in the DMZ**
 1194 **to a Workstation in the Testbed LAN**

Event 19299 03:01:39 PM · Apr 12, 2021 RDP Connection (Authenticated) **Medium** Not resolved

<p>Details</p> <p>Source</p> <p>Destination</p> <p>Policy</p> <p>Status</p>	<p>An authenticated initiation of an RDP connection</p> <table border="1"> <tr> <td>SOURCE NAME</td> <td>HistorianDMZ</td> </tr> <tr> <td>SOURCE ADDRESS</td> <td>10.100.1.4</td> </tr> <tr> <td>DESTINATION NAME</td> <td>NESSUSVM</td> </tr> <tr> <td>DESTINATION ADDRESS</td> <td>10.100.0.25</td> </tr> <tr> <td>PROTOCOL</td> <td>Rdshls</td> </tr> <tr> <td>COOKIE</td> <td>Cookie: msthash=ncceuser</td> </tr> </table>	SOURCE NAME	HistorianDMZ	SOURCE ADDRESS	10.100.1.4	DESTINATION NAME	NESSUSVM	DESTINATION ADDRESS	10.100.0.25	PROTOCOL	Rdshls	COOKIE	Cookie: msthash=ncceuser	<p>Why is this important?</p> <p>Remote access to a workstation is a common way for cyber threats to propagate towards their target. Often system administrators prefer to limit use of such protocols to unique support cases so that they can identify the use of such protocols as anomalies.</p>	<p>Suggested Mitigation</p> <ol style="list-style-type: none"> 1. Check if this communication was approved. 2. Investigate if it was done by an authorized employee. 3. Check for potential initiation of such a communication by malware.
SOURCE NAME	HistorianDMZ														
SOURCE ADDRESS	10.100.1.4														
DESTINATION NAME	NESSUSVM														
DESTINATION ADDRESS	10.100.0.25														
PROTOCOL	Rdshls														
COOKIE	Cookie: msthash=ncceuser														

1195 **Figure D-14: Attempt to Execute 1.exe Failed**1196 **D.2.2 Build 2**1197 **D.2.2.1 Configuration**

- 1198 ▪ Application Allowlisting: Windows SRP
 - 1199 • Allowlisting policies are applied to systems in the DMZ, Testbed LAN, and PCS VLAN 1 and
 - 1200 2.
- 1201 ▪ Behavior Anomaly Detection: eyeInspect
 - 1202 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

1203 **D.2.2.2 Test Results**

1204 [Figure D-15](#) shows the RDP alert for connection into the DMZ while [Figure D-16](#) shows the details of the

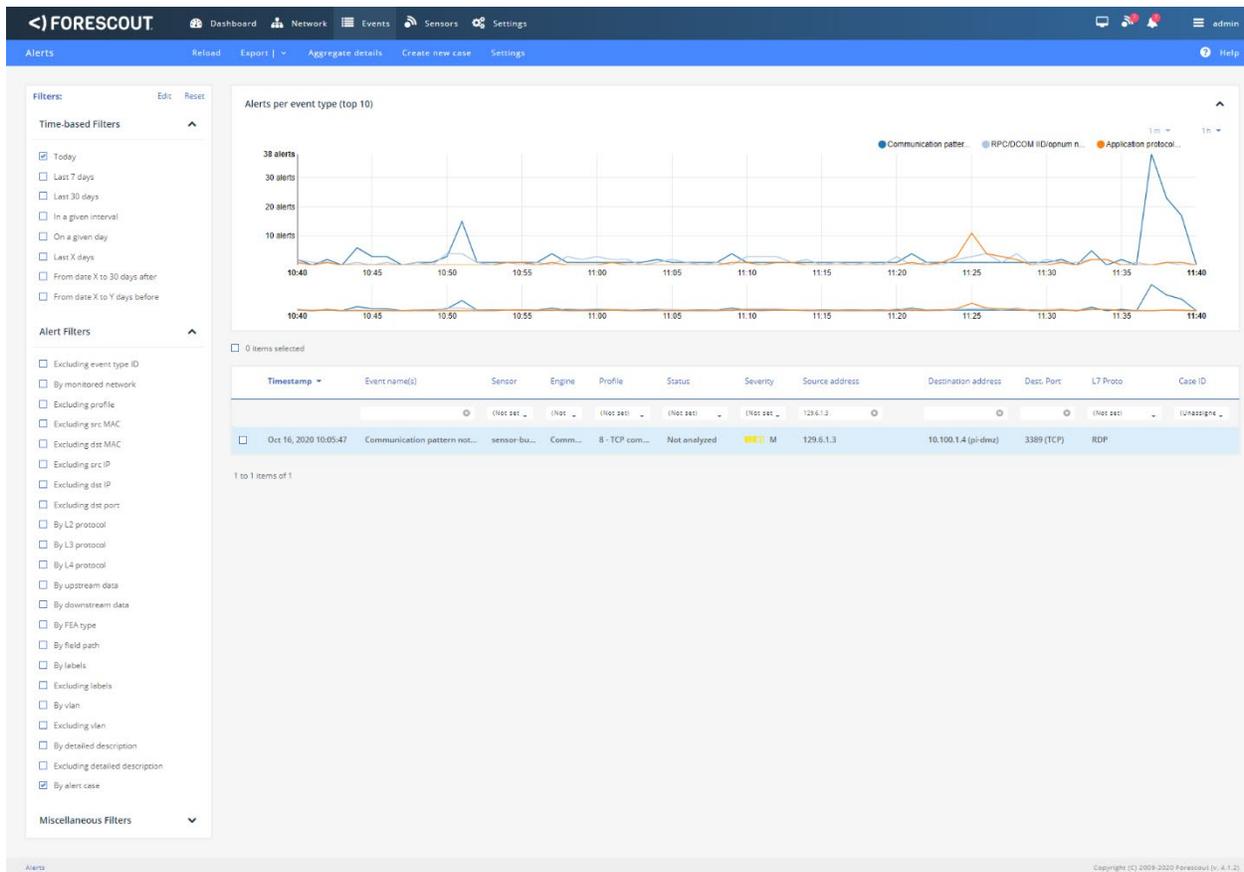
1205 alert. [Figure D-17](#) shows a collection of suspicious activity detected by Forescout eyeInspect when

1206 scanning and an RDP connection is executed. [Figure D-18](#) and [Figure D-19](#) show details of a port

1207 scanning alert and the second RDP connection into the manufacturing environment, respectively. The

1208 attempt to execute malware (1.exe) is blocked by Windows SRP as shown in [Figure D-20](#).

1209 Figure D-15: Alert Dashboard Showing Detection of an RDP Session



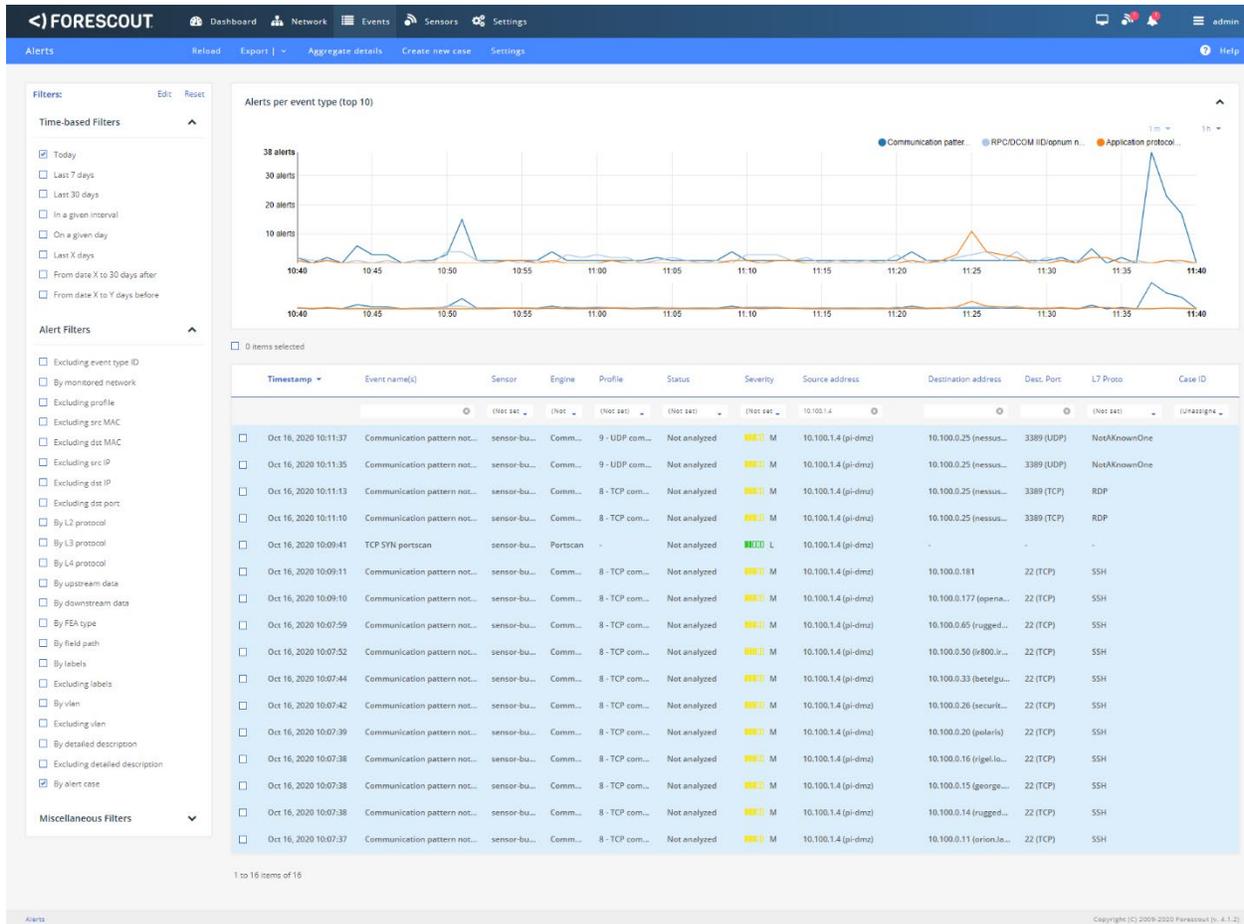
1210 Figure D-16: Details of the Detected RDP Session Activity from an External System to DMZ System

The screenshot displays the 'Alert details' page in the Forescout interface. The page is divided into several sections:

- Summary:**
 - Alert ID: 203138
 - Timestamp: Oct 16, 2020 10:05:47
 - Sensor name: sensor-bundle-ncscope
 - Detection engine: Communication patterns (LAN CP)
 - Profile: 8 - TCP communications
 - Severity: Medium
 - Source MAC: (Cisco)
 - Destination MAC: (Microsoft) **Corporate Workstation**
 - Source IP: (ip-dmz)
 - Destination IP: (ip-dmz)
 - Source port: 49932
 - Destination port: 3389
 - L2 proto: Ethernet
 - L3 proto: IP
 - L4 proto: TCP
 - L7 proto: RDP
 - TCP stream opened in hot start mode: false
 - Status: Not analyzed
- Monitored networks:**

Name	Address	VLAN IDs
DMZ LAN	10.100.1.0/24	any
- Source host info:**
 - IP address: (Public IP)
 - Host MAC addresses: Unknown
 - Other observed MAC addresses: (Rockwell), (Cisco)
 - Role: Terminal client
 - Vendor and model: Rockwell
 - Client protocols: RDP (TCP 3389)
 - Server protocols: NooKnownOne (TCP 4444)
 - Purdue level: 4 - Site business network
 - Security Risk: 3.3
 - Operational Risk: 0.0
 - Criticality: L
 - Known vulnerabilities: 0
 - Related alerts: 6 (Show)
 - First seen: Oct 14, 2020 11:56:54
 - Last seen: Oct 16, 2020 10:16:45
- Destination host info:**
 - IP address: (Private IP)
 - Host name: ip-dmz
 - Other host names: (Microsoft)
 - Host MAC addresses: (Last seen: Oct 16, 2020 10:46:57)
 - Other observed MAC addresses: (Rockwell), (Ruggedco), (Cisco)
 - Role: Terminal server
 - Other roles: Windows workstation, Terminal client
 - OS version: Windows 10 or Windows Server 2016
 - Client protocols:
 - AFR (TCP 445)
 - DCOM (TCP 135)
 - DNS (UDP 53, 5353, 5315)
 - FailedConnection (TCP 21, 71, 98, 110, 389, 8834, 49179, 49195, 54128, 62531, 62532, 62841, 62899)
 - HTTP (TCP 80, 445, 8530)
 - Netbios (TCP 445)
 - LDAP (TCP 445)
 - MSSQL (TCP 445)
 - NTP (UDP 123)
 - NetBIOS (UDP 137)
 - NoData (TCP 139)
 - NooKnownOne (TCP 445)
 - NooKnownOne (UDP 442, 1434, 1514, 3389, 32904, 43463, 43724, 43724, 43799, 44102, 44699)
 - OssoftR (TCP 5450)
 - RDP (TCP 3389)
 - SMB (TCP 445)
 - SMB (TCP 138)
 - SSDP (UDP 1900)
 - SSH (TCP 22)
 - SSL (TCP 443, 445)
 - SunRPC (TCP 445)
 - WS_Discovery (UDP 3702)
 - FailedConnection (TCP 1542, 1574, 1577, 1585, 2311, 28860, 49690, 49934)
 - NetBIOS (TCP 139)
 - RDP (TCP 3389)
 - SMB (TCP 445)
 - SSL (TCP 5671, 5672)
 - Server protocols:
 - RDP (TCP 3389)
 - SMB (TCP 445)
 - SSL (TCP 5671, 5672)
 - Labels: vlan_id=1
 - Purdue level: 3 - Site operations and control
 - Security Risk: 6.0
 - Operational Risk: 2.0
 - Criticality: L
 - Known vulnerabilities: 0
 - Related alerts: 922 (Show)
 - First seen: Sep 3, 2020 16:47:58
 - Last seen: Oct 16, 2020 11:45:43
- Alert Details:**
 - ID and name: lan_cp_cmw_c - Communication pattern not whitelisted
 - Description: Communication pattern not whitelisted: the source and destination hosts are whitelisted in some communication rule, but not with this combination
 - Triggering rule/default action: alert

1211 Figure D-17: Detection of Scanning Traffic and RDP Connection into Manufacturing Environment



1213 Figure D-19: Details of Alert for RDP Connection into Manufacturing Environment

Summary

Alert ID: 203188
 Timestamp: Oct 16, 2020 10:11:10
 Sensor name: sensor-bundle-nccoe
 Detection engine: Communication patterns (LAN CP)
 Profile: 8 - TCP communications
 Severity: ■ ■ ■ Medium
 Source MAC: 00:15:5D:02:0D:03 (Microsoft)
 Destination MAC: 7C:DE:CE:67:86:88 (Cisco)
 Source IP: ● 10.100.1.4 (pi-dmz)
 Destination IP: ● 10.100.0.25 (nessusvm)
 Source port: 3733
 Destination port: 3389
 L2 proto: Ethernet
 L3 proto: IP
 L4 proto: TCP
 L7 proto: RDP
 TCP stream opened in hot start mode: false
 Status: Not analyzed
 Labels:
 User notes:

Monitored networks

Name	Address	VLAN IDs
DMZ LAN	10.100.1.0/24	any
Lab LAN	10.100.0.0/24	any

Source host info

IP address: 10.100.1.4 (Private IP)
 Host name: pi-dmz
 Other host names: ruggedcom.mgmt.lab
 Host MAC addresses: 00:15:5D:02:0D:03 (Microsoft)
 Last seen: Oct 16, 2020 11:47:52
 Other observed MAC addresses: E4:90:59:3B:C2:C2 (Rockwell), 94:BB:C5:0E:E1:9F (Ruggedcom), 7C:DE:CE:67:86:88 (Cisco)
 Role: Terminal server
 Other roles: Windows workstation, Terminal client
 OS version: Windows 10 or Windows Server 2016
 Client protocols: AFP (TCP 445), DICOM (TCP 139), DNS (UDP 53, 5355), FailedConnection (TCP 21, 71, 98, 110, 389, 8034, 49179, 49195, 54128, 62331, 62332, 62841, 62899), HTTP (TCP 80, 443, 8530), Kerberos (TCP 445), LDAP (TCP 445), MSSQL (TCP 443), NTP (UDP 123), NetBIOS (UDP 137), NoData (TCP 139), NotKnownOne (TCP 445), NotKnownOne (UDP 443, 1434, 1514, 3389, 32904, 43463, 43724, 43734, 43739, 44102, 44690), OpenSSH (TCP 5450), RDP (TCP 3389), SMB (TCP 445), SMB (TCP 138), SDDP (UDP 1500), SSH (TCP 22), SSL (TCP 443, 445), SunRPC (TCP 445), WS_Discovery (UDP 3702), FailedConnection (TCP 1542, 1574, 1577, 1585, 2311, 28860, 49690, 49694)
 Server protocols: NetBIOS (TCP 139), RDP (TCP 3389), SMB (TCP 445), SSL (TCP 5671, 5672)
 Labels: vlan_ids=1
 Purdue level: 3 - Site operations and control
 Security Risk: ■ ■ ■ 6.0
 Operational Risk: ■ ■ ■ ■ 2.0
 Criticality: ■ ■ ■ ■ L
 Known vulnerabilities: 0
 Related alerts: 923 (Show)
 First seen: Sep 3, 2020 16:47:58
 Last seen: Oct 16, 2020 11:48:50

Destination host info

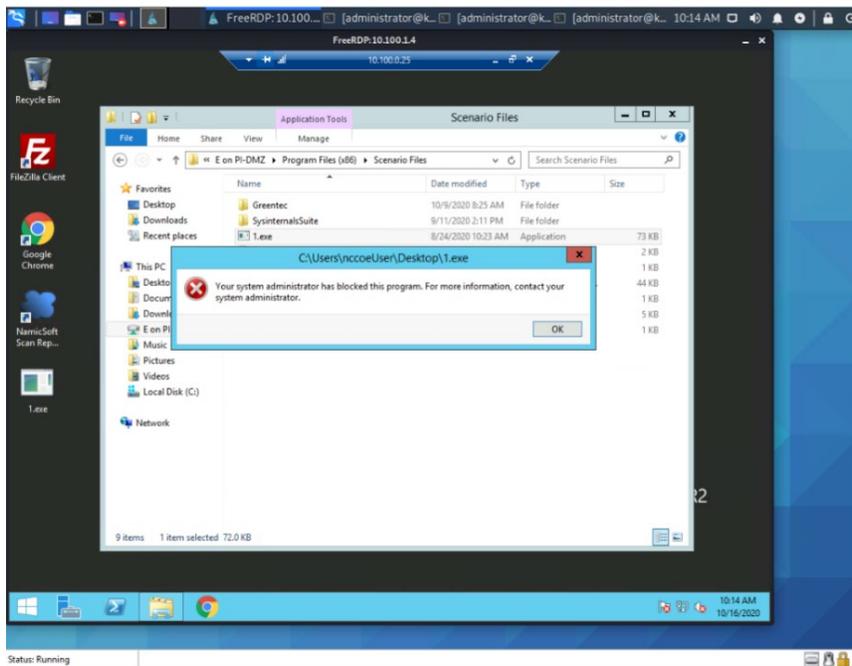
IP address: 10.100.0.25 (Private IP)
 Host name: nessusvm
 Other host names: ruggedcom.mgmt.lab
 Host MAC addresses: 00:15:5D:02:0A:06 (Microsoft)
 Last seen: Oct 16, 2020 11:45:39
 Other observed MAC addresses: 94:BB:C5:0E:E1:9F (Ruggedcom), 7C:DE:CE:67:86:88 (Cisco)
 Role: Terminal server
 Other roles: Windows workstation, Terminal client
 OS version: Windows 8.1 or Windows Server 2012 R2
 Client protocols: DNS (UDP 5353, 5355), HTTP (TCP 80), LLDP (LLDP), NetBIOS (UDP 137), NotKnownOne (TCP 4444), NotKnownOne (UDP 443), RDP (TCP 3389), SMB (TCP 445), SMB (UDP 138), SDDP (UDP 1500), SSH (TCP 22), SSL (TCP 443), DICOM (TCP 135), FailedConnection (TCP 21, 22, 53, 71, 80, 98, 110, 111, 389, 443, 5555, 5891, 5901, 6667, 7777, 7878, 8080, 8834, 49179, 49195)
 Server protocols: NetBIOS (UDP 137), NoData (TCP 139), NotKnownOne (UDP 1434, 3389, 6838, 31037, 34734, 47455), RDP (TCP 3389), SMB (TCP 445)
 Purdue level: 3 - Site operations and control
 Security Risk: ■ ■ ■ 6.0
 Operational Risk: ■ ■ ■ ■ 0.0
 Criticality: ■ ■ ■ ■ L
 Known vulnerabilities: 0
 Related alerts: 1063 (Show)
 First seen: Sep 3, 2020 16:57:16
 Last seen: Oct 16, 2020 11:48:19

Alert Details

ID and name: lan_cp_cmvw_c - Communication pattern not whitelisted
 Description: Communication pattern not whitelisted: the source and destination hosts are whitelisted in some communication rule, but not with this combination
 Triggering rule/default action: alert

Alerts / Alert details Copyright (C) 2009-2020 Forescout (v. 4.1.2)

1214 Figure D-20: Dialog Message Showing 1.exe was Blocked from Executing



1215 D.2.3 Build 3

1216 *D.2.3.1 Configuration*

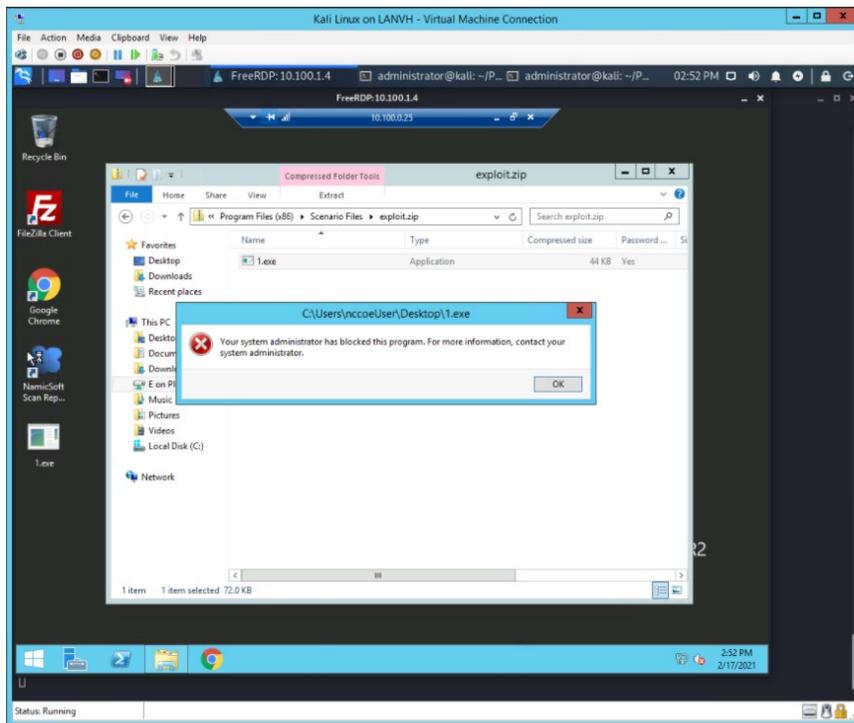
- 1217 ▪ Application Allowlisting: Windows SRP
 - 1218 • Allowlisting policies are applied to systems in the DMZ, Testbed LAN, and Supervisory LAN
- 1219 ▪ Behavior Anomaly Detection: Dragos
 - 1220 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1221 Control LAN.

1222 *D.2.3.2 Test Results*

1223 Windows SRP blocks the attempted execution of 1.exe (Figure D-21). Figure D-22 shows the alerts
 1224 generated by Dragos when it detected the remote connection to the target. Figure D-23 depicts the
 1225 detected RDP session from an external system to the DMZ system. Figure D-24 depicts network scanning
 1226 alert details. Figure D-25 depicts the RDP session from a DMZ system to the Testbed LAN system.

DRAFT

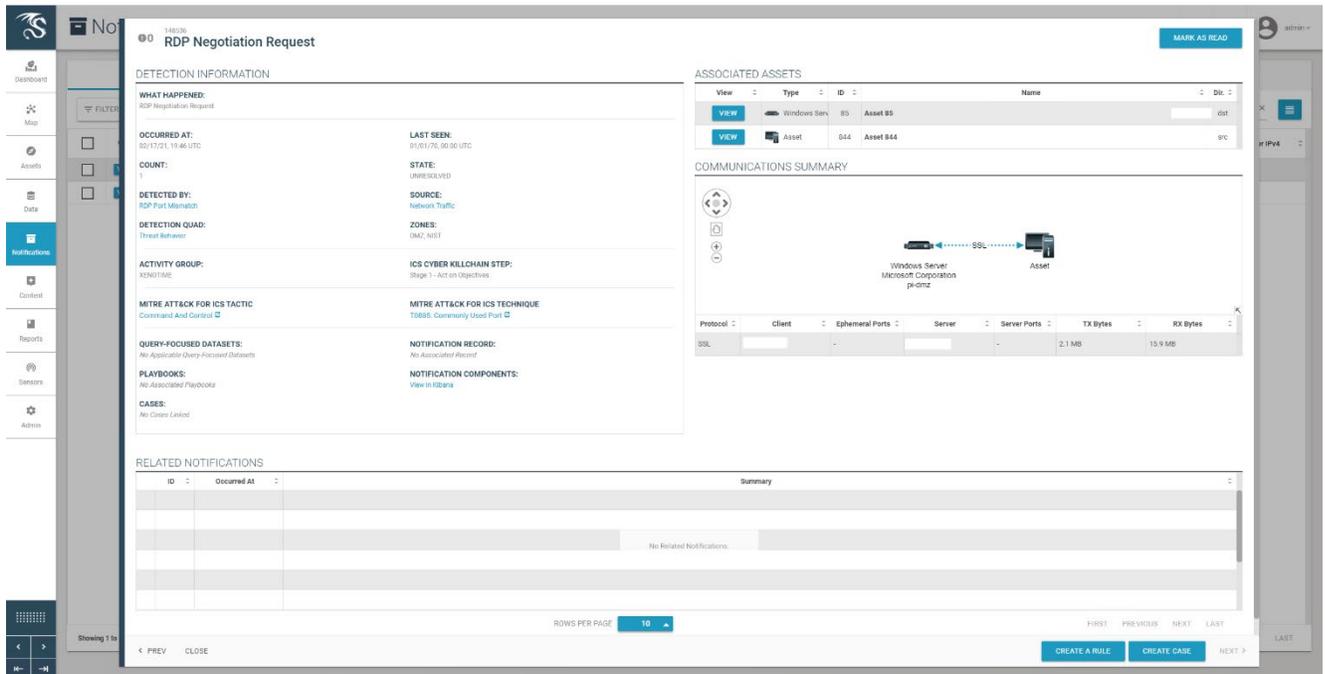
1227 Figure D-21: Windows SRP blocked 1.exe From Executing



1228 Figure D-22: Log of Alerts Detected by Dragos

View	Sever.	ID	Occurred At	Detection Quadrants	Summary	Message	Detected By	Asset IDs	Source IPv4	Dest. IPv4	Other IPv4	
<input type="checkbox"/>	VIEW	1	148546	02/17/21, 07:39:49...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 85 (IP:) connected to Asset...	Network Device Access	85, 96			
<input type="checkbox"/>	VIEW	1	148545	02/17/21, 07:37:59...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 85 (IP:) connected to Asset...	Network Device Access	85, 96			
<input type="checkbox"/>	VIEW	1	148544	02/17/21, 07:38:14...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148543	02/17/21, 07:42:57...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 85 (IP:) connected to Asset...	Network Device Access	85, 96			
<input type="checkbox"/>	VIEW	1	148542	02/17/21, 07:42:40...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148541	02/17/21, 07:43:46...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148540	02/17/21, 07:44:53...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148539	02/17/21, 07:40:27...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	0	148538	02/17/21, 07:46:11...	Indicator	Default Community Signature Fired	Activity that meets the criteria of a default co...	Short Community Rules	85, 844			
<input type="checkbox"/>	VIEW	0	148537	02/17/21, 07:46:11...	Indicator	Default Community Signature Fired	Activity that meets the criteria of a default co...	Short Community Rules	85, 844			
<input type="checkbox"/>	VIEW	0	148536	02/17/21, 07:46:11...	Threat Behavior	RDP Negotiation Request	RDP Negotiation Request	RDP Port Mismatch	85, 844			
<input type="checkbox"/>	VIEW	1	148531	02/17/21, 07:36:02...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148530	02/17/21, 07:38:15...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			
<input type="checkbox"/>	VIEW	1	148529	02/17/21, 07:37:08...	Threat Behavior	Administrative Access to a Network Device D...	Asset: 1807 (IP:) connected to ...	Network Device Access	1807, 94			

1229 Figure D-23: Detail of RDP Session Activity Between an External System and a DMZ System



1230 Figure D-24: Detail for Network Scanning Alert

Sequential Scan Detected MARK AS READ

DETECTION INFORMATION

WHAT HAPPENED: Sequential ICMP Sweep Detected

OCCURRED AT: 02/17/21, 02:50 PM EST **LAST SEEN:** 12/31/99, 07:00 PM EST

COUNT: 1 **STATE:** UNRESOLVED

DETECTED BY: Scan Sequential **SOURCE:** Network Traffic

DETECTION QUAD: Threat Behavior **ZONES:** DMZ

ACTIVITY GROUP: ELECTRIUM **ICS CYBER KILLCHAIN STEP:** Stage 1 - Reconnaissance

MITRE ATT&CK FOR ICS TACTIC: Discovery ID **MITRE ATT&CK FOR ICS TECHNIQUE:** T0846: Remote System Discovery ID

QUERY-FOCUSED DATASETS: Scanning **NOTIFICATION RECORD:** No Associated Record

PLAYBOOKS: Network Address Scanning Activity Detected **NOTIFICATION COMPONENTS:** No Associated Components

CASES: No Cases Linked

ASSOCIATED ASSETS

View	Type	ID	Name	Dir
VIEW	Windows Serv	85	Asset 85	10.100.1.4 other

COMMUNICATIONS SUMMARY

No Communications Summary

RELATED NOTIFICATIONS

ID	Occurred At	Summary
No Related Notifications.		

[PREV](#) [CLOSE](#) [CREATE A RULE](#) [CREATE CASE](#) [NEXT](#)

1231 Figure D-25: Detail of RDP Session Activity Between a DMZ System and a Testbed LAN System

RDP Negotiation Request MARK AS READ

DETECTION INFORMATION

WHAT HAPPENED: RDP Negotiation Request

OCCURRED AT: 02/17/21, 16:51 UTC **LAST SEEN:** 01/01/70, 00:00 UTC

COUNT: 1 **STATE:** UNRESOLVED

DETECTED BY: RDP First Minimize **SOURCE:** Network Traffic

DETECTION QUAD: Threat Behavior **ZONES:** DMZ, Cybersecurity LAN

ACTIVITY GROUP: XE3NOTIME **ICS CYBER KILLCHAIN STEP:** Stage 1 - Act on Objectives

MITRE ATT&CK FOR ICS TACTIC: Command and Control ID **MITRE ATT&CK FOR ICS TECHNIQUE:** T0885: Commonly Used Port ID

QUERY-FOCUSED DATASETS: No Applicable Query-Focused Datasets **NOTIFICATION RECORD:** No Associated Record

PLAYBOOKS: No Associated Playbooks **NOTIFICATION COMPONENTS:** View in Kitana

CASES: No Cases Linked

ASSOCIATED ASSETS

View	Type	ID	Name	Dir
VIEW	Windows Serv	85	Asset 85	10.100.1.4 src
VIEW	Vulnerability S	37	Asset 37	10.100.0.25 dst

COMMUNICATIONS SUMMARY

Network diagram showing ICMP, SSL, and UDP traffic between Windows Server (10.100.1.4) and General Use Desktop (10.100.0.25).

Protocol	Client	Ephemeral Ports	Server	Server Ports	TX Bytes	RX Bytes
ICMP	10.100.1.4	-	10.100.0.25	-	222.0 bytes	148.0 bytes
ICMP	10.100.0.25	-	10.100.1.4	-	148.0 bytes	222.0 bytes
SSL	10.100.1.4	53365, 53367	10.100.0.25	3389	1.2 MB	2.0 MB
UDP	10.100.1.4	56180, 56181	10.100.0.25	3389	14.9 KB	0 bytes

RELATED NOTIFICATIONS

ID	Occurred At	Summary
No Related Notifications.		

ROWS PER PAGE: 10 [FIRST](#) [PREVIOUS](#) [NEXT](#) [LAST](#)

[PREV](#) [CLOSE](#) [CREATE A RULE](#) [CREATE CASE](#) [NEXT](#)

1232 **D.2.4 Build 4**

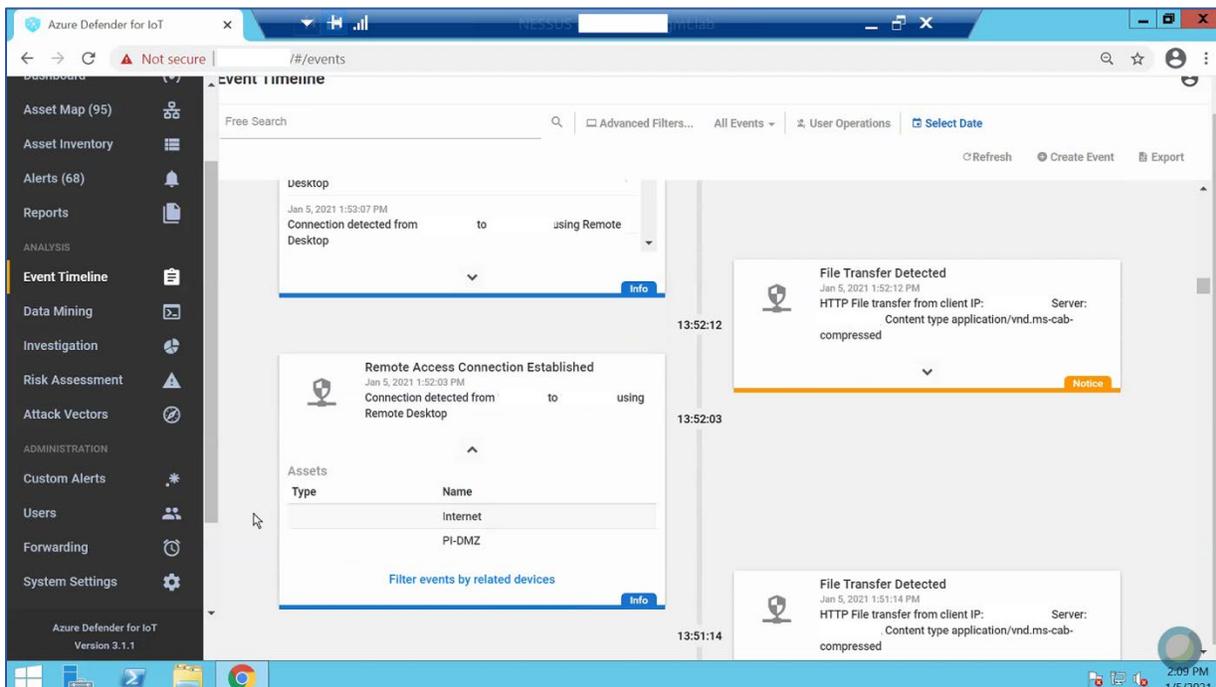
1233 *D.2.4.1 Configuration*

- 1234 ▪ Application Allowlisting: Carbon Black
 - 1235 • Agent installed on systems in the DMZ, Testbed LAN, and Supervisory LAN and configured
 - 1236 to communicate to the Carbon Black Server.
- 1237 ▪ Behavior Anomaly Detection: Azure Defender for IoT
 - 1238 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1239 Control LAN.

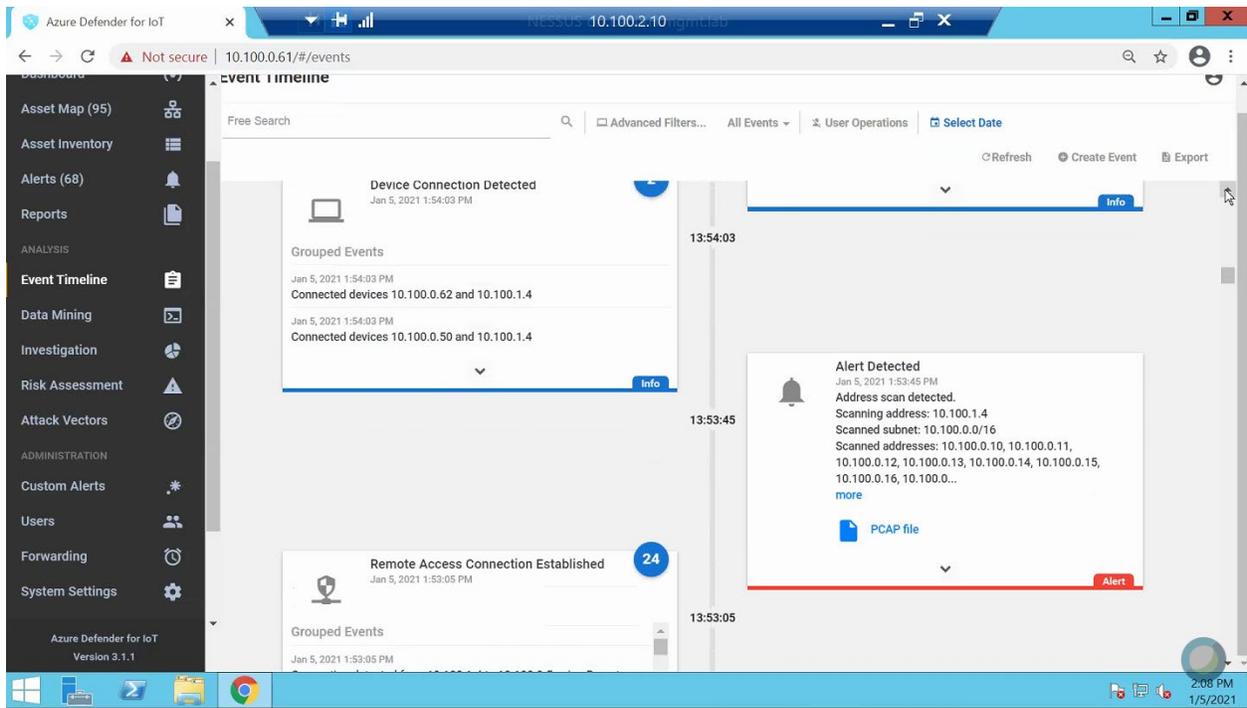
1240 *D.2.4.2 Test Results*

1241 Azure Defender for IoT is able to detect the remote access connection to the DMZ as seen in [Figure D-](#)
1242 [26](#). [Figure D-27](#) shows detection of scanning activity, while [Figure D-28](#) shows details of the scan. The
1243 RDP connection into the manufacturing environment is seen in [Figure D-29](#). Carbon Black blocks 1.exe
1244 from executing as shown in [Figure D-30](#).

1245 **Figure D-26: Azure Defender for IoT “info” Event Identified the Remote Access Connection to the DMZ**



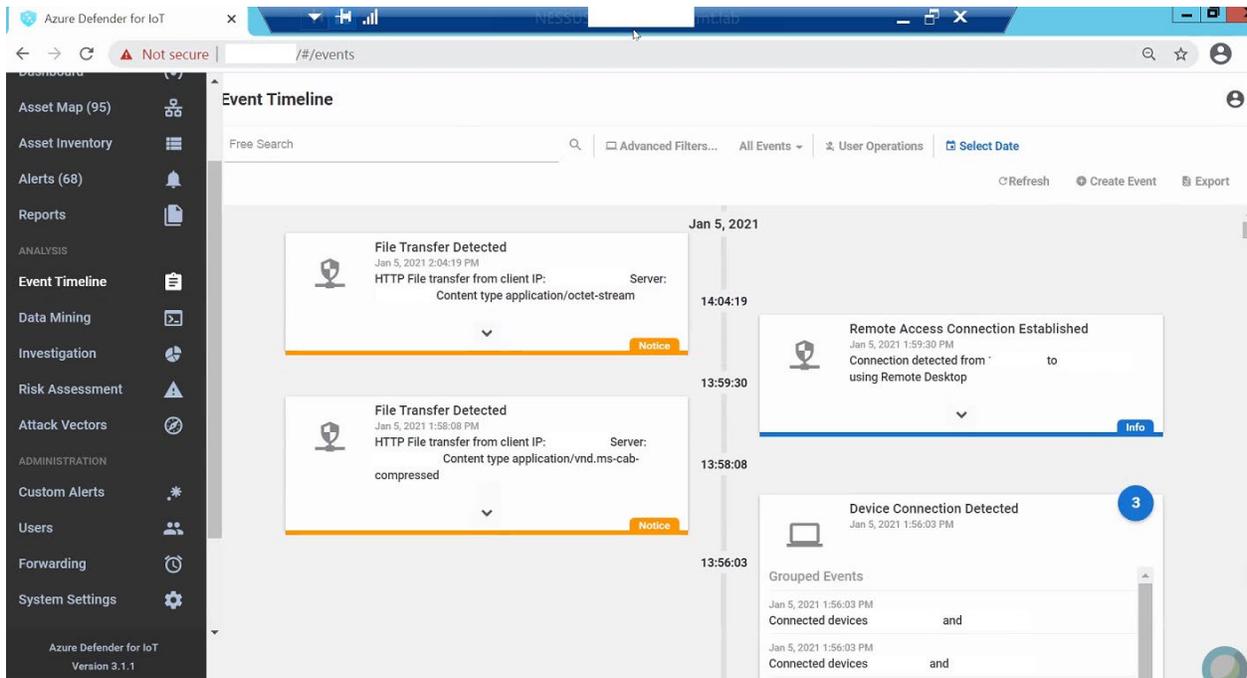
1246 Figure D-27: Alert for Scanning Activity

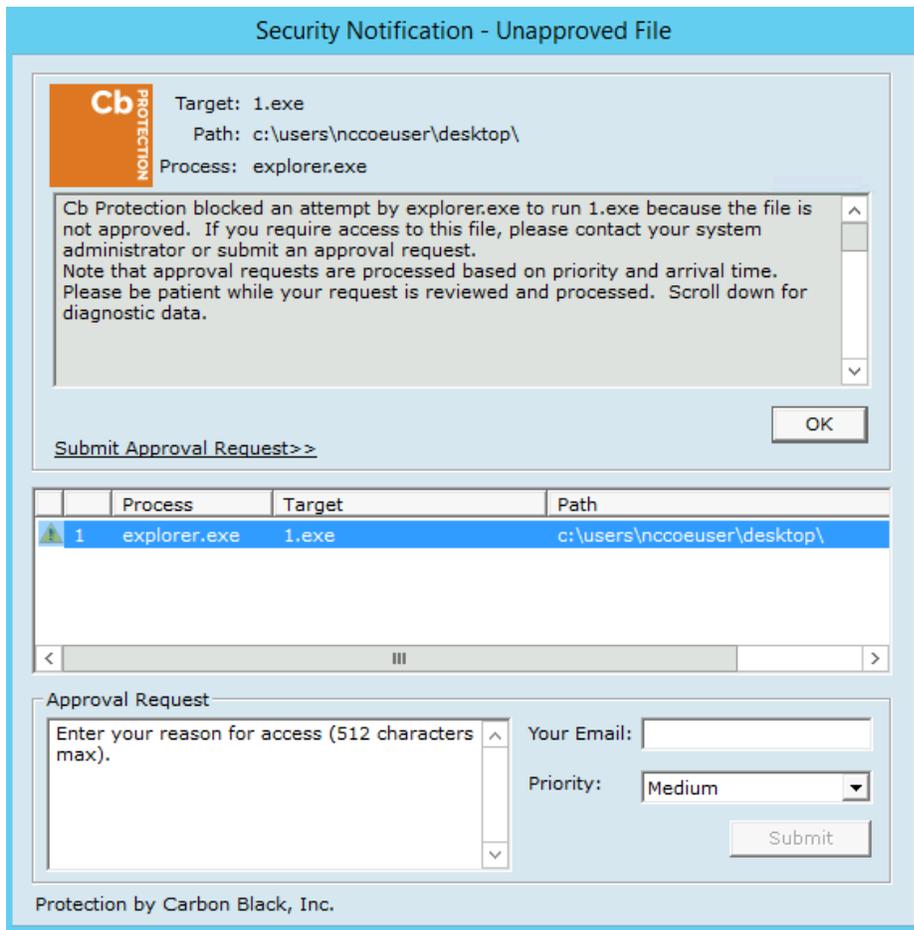


1247 Figure D-28: Details for the Scanning Alert

The screenshot displays a security alert interface. At the top left, it shows 'ID: 183'. On the top right, there are several utility icons: a list, a plus sign, a download arrow, a document icon, a pin, and a close 'X' icon. The main heading is 'Address Scan Detected' in bold. Below it, the text reads 'Anomaly | Jan 5, 2021 1:53:44 PM (12 minutes ago)'. The alert details include: 'Address scan detected.', 'Scanning address: 10.100.1.4', 'Scanned subnet: 10.100.0.0/16', and 'Scanned addresses: 10.100.0.10, 10.100.0.11, 10.100.0.12, 10.100.0.13, 10.100.0.14, 10.100.0.15, 10.100.0.16, 10.100.0.17, 10.100.0.18, 10.100.0.19...'. A recommendation states: 'It is recommended to notify the security officer of the incident.' Below this is a small icon of a server rack and the label 'PI-DMZ'. A section titled 'Manage this Event' contains two bullet points: '● Multiple scans in the network can be an indication for a new device in the network, a new functionality of an existing device, improper configuration of an application (for example: due to a firmware update, or a new deployment), or malicious activity in the network, such as reconnaissance.' and '● During the reconnaissance phase, a tool usually collects system configuration data, including data about any installed antivirus applications and steals data on the computer systems themselves, which is then sent back to the attackers.' At the bottom right, there are two blue buttons: 'Learn' and 'Acknowledge'.

1248 Figure D-29: Detection of RDP Connection into the Manufacturing Environment



1249 **Figure D-30: Carbon Black Shows an Alert for Blocking File 1.exe**

1250 **D.3 Executing Scenario 3: Protect Host from Malware via Remote Access**

1251 **Connections**

1252 An authorized user with an authorized remote workstation, infected with a worm-type malware,
1253 connects via remote access capabilities to the manufacturing environments. The malware on the remote
1254 host attempts to scan the manufacturing environment to identify vulnerable hosts. The expected result
1255 is that the remote access tools effectively stop the worm-type malicious code from propagating to the
1256 manufacturing environment from the infected remote workstation.

1257 **D.3.1 Build 1**

1258 *D.3.1.1 Configuration*

- 1259 ▪ Remote Access: Cisco VPN
 - 1260 • Configured to allow authorized VPN users to access to ConsoleWorks web interface.
- 1261 ▪ User Authentication/User Authorization: ConsoleWorks

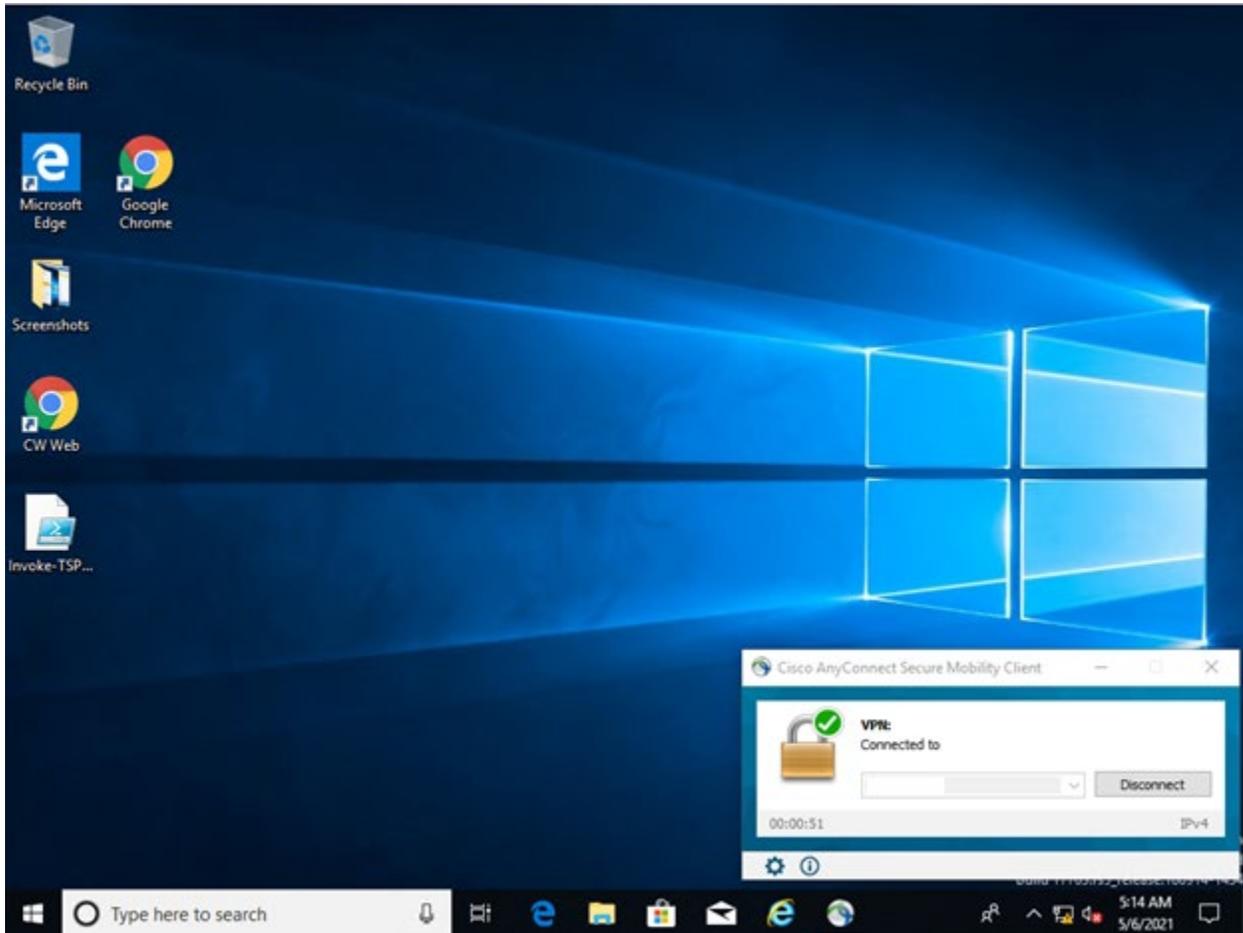
DRAFT

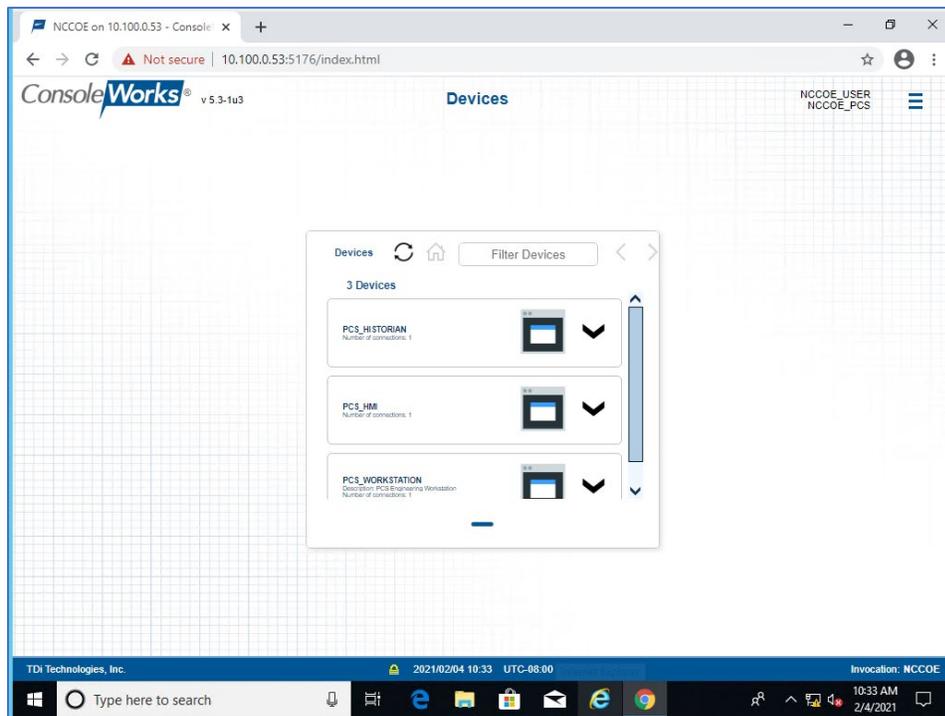
- 1262 • Configured for access PCS environment.

1263 *D.3.1.2 Test Results*

1264 [Figure D-31](#) shows the remote connection being established through the Cisco AnyConnect VPN
1265 application through which a browser is used to access the ConsoleWorks web interface ([Figure D-32](#)).
1266 Once a connection to ConsoleWorks was established, the simulated worm attack was executed on the
1267 remote PC to scan the target network. The scan was successfully blocked by the VPN configuration.

1268 **Figure D-31: Secured VPN Connection to Environment with Cisco AnyConnect**



1269 **Figure D-32: Remote Access is Being Established Through ConsoleWorks**1270 **D.3.2 Build 2**1271 **D.3.2.1 Configuration**

- 1272 ▪ Remote Access, User Authentication/User Authorization: Dispel
- 1273 • Dispel VDI is configured to allow authorized users to access PCS environment through the
- 1274 Dispel Enclave to the Dispel Wicket.

1275 **D.3.2.2 Test Results**

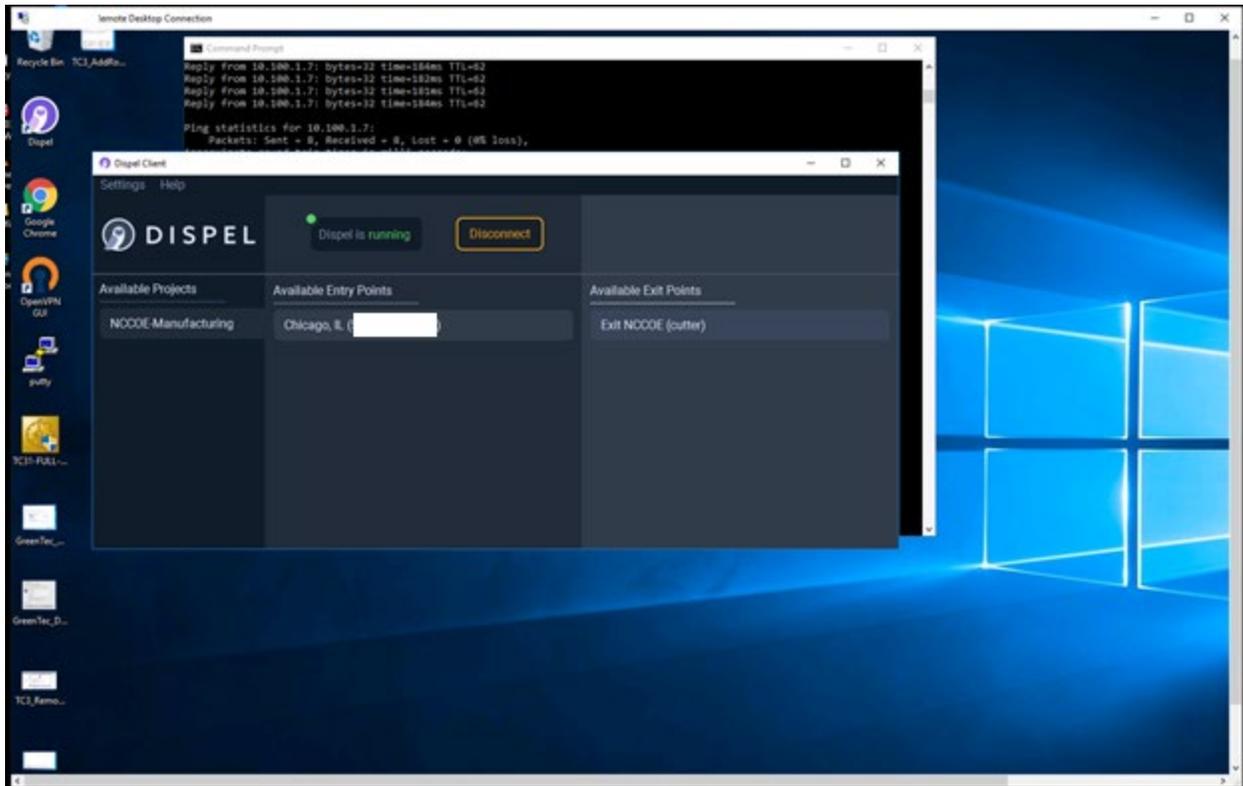
1276 The user connects to the Dispel VDI as shown in [Figure D-33](#) and then connects to the PCS workstation

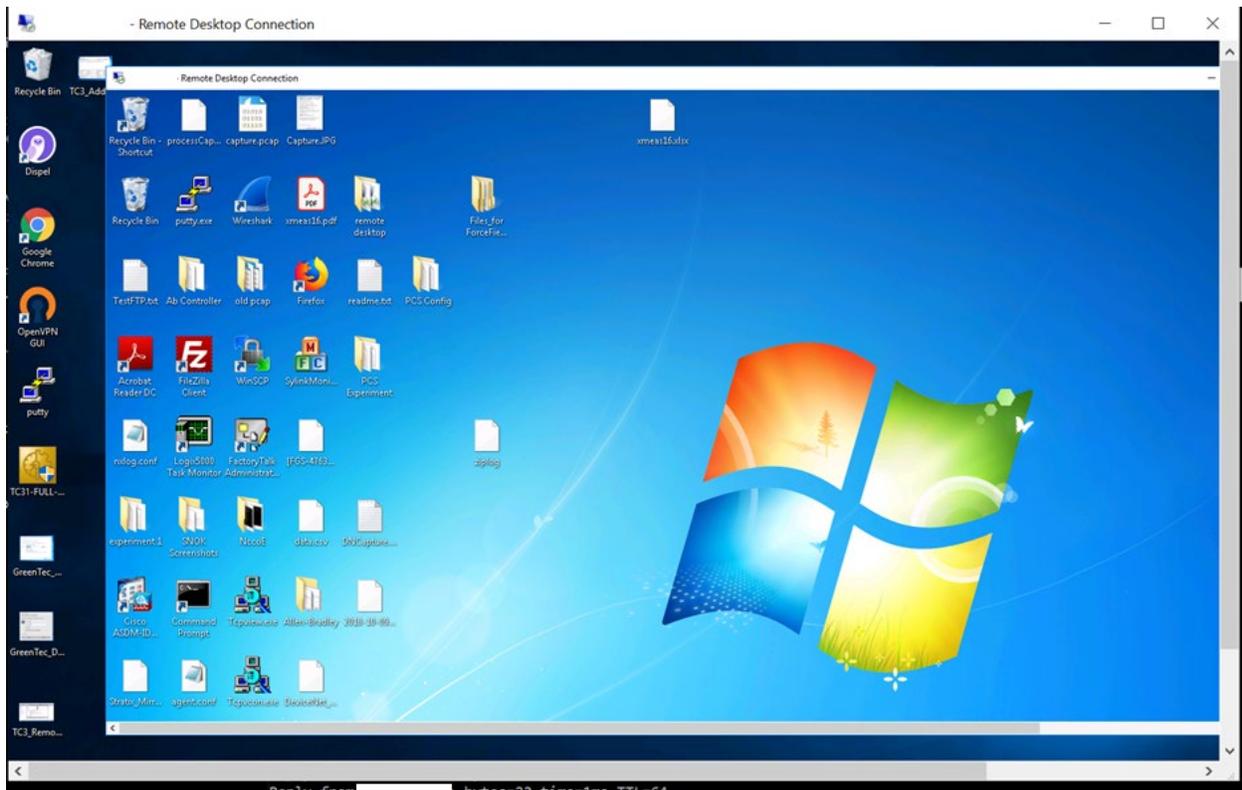
1277 as shown in [Figure D-34](#). Once a connection to the NCCOE environment was established, the simulated

1278 worm attack was executed on the remote PC to scan the target network. The scan was successfully

1279 blocked by the Dispel VDI configuration.

1280 Figure D-33: Dispel VDI with Interface for Connecting Through Dispel Enclave to Dispel Wicket ESI



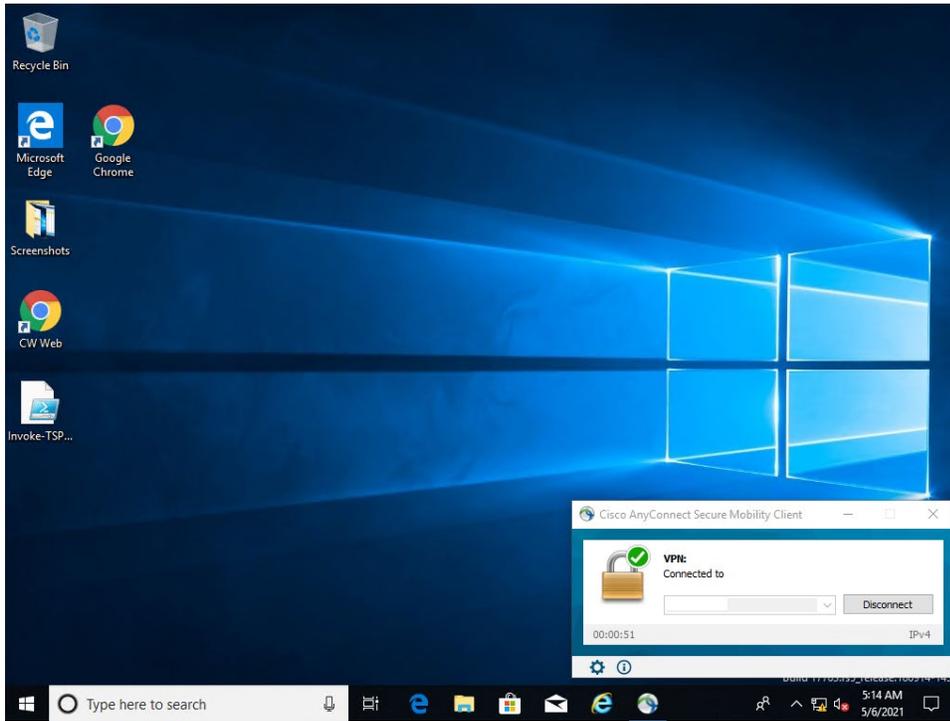
1281 **Figure D-34: Nested RDP Session Showing Dispel Connection into the PCS Workstation**1282 **D.3.3 Build 3**1283 *D.3.3.1 Configuration*

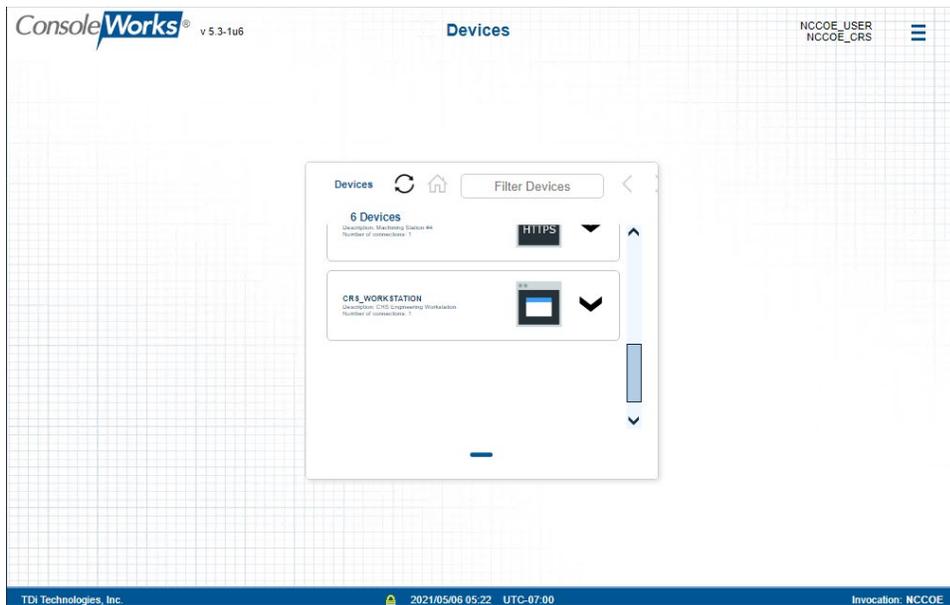
- 1284 ▪ Remote Access: Cisco VPN
 - 1285 • Configured to allow authorized VPN users to access to ConsoleWorks web interface.
- 1286 ▪ User Authentication/User Authorization: ConsoleWorks
 - 1287 • Configured for access CRS environment.

1288 *D.3.3.2 Test Results*

1289 [Figure D-35](#) shows the remote connection being established through the Cisco AnyConnect VPN
 1290 application, where a browser is used to access the ConsoleWorks web interface ([Figure D-36](#)). Once a
 1291 connection to ConsoleWorks was established, the simulated worm attack was executed on the remote
 1292 PC to scan the target network. The scan was successfully blocked by the VPN configuration.

1293 Figure D-35: VPN Connection to Manufacturing Environment



1294 **Figure D-36: Remote Access is Being Established Through ConsoleWorks**1295 **D.3.4 Build 4**1296 ***D.3.4.1 Configuration***

- 1297 ▪ Remote Access, User Authentication/User Authorization: Dispel
- 1298 • Dispel VDI is configured to allow authorized users to access the PCS environment through
- 1299 the Dispel Enclave to the Dispel Wicket.

1300 ***D.3.4.2 Test Results***

1301 [Figure D-37](#) shows the Dispel VDI desktop, which allows a connection to the CRS workstation in

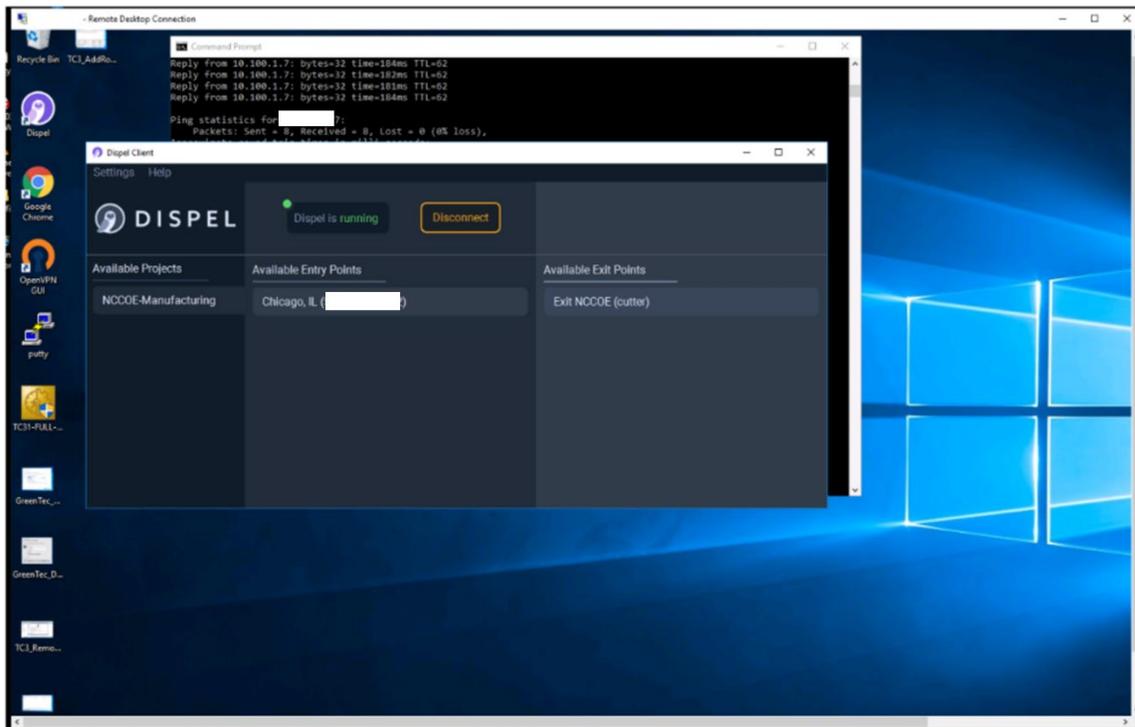
1302 [Figure D-38](#). Once a connection to the NCCOE environment was established, the simulated worm attack

1303 was executed on the remote PC to scan the target network. The scan was successfully blocked by the

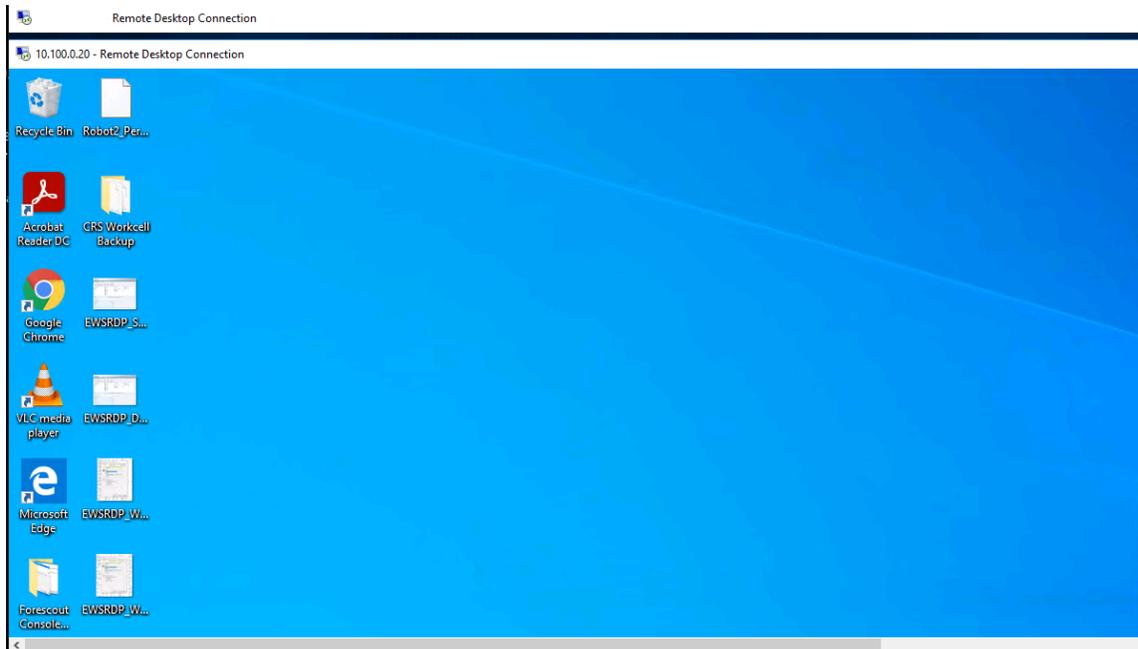
1304 use of the Dispel VDI.

DRAFT

1305 Figure D-37: Dispel VDI Showing Interface for Connecting Through Dispel Enclave to Dispel Wicket



1306 Figure D-38: Nested RDP Session Showing Dispel Connection into the CRS Workstation



1307 **D.4 Executing Scenario 4: Protect Host from Unauthorized Application** 1308 **Installation**

1309 An authorized user copies downloaded software installation files and executable files from a shared
1310 network drive to a workstation. The user attempts to execute or install the unauthorized software on
1311 the workstation. The expected result is that the application allowlisting tool prevents execution or
1312 installation of the software. Also, the behavioral anomaly detection identifies file transfer activity in the
1313 manufacturing environment.

1314 **D.4.1 Build 1**

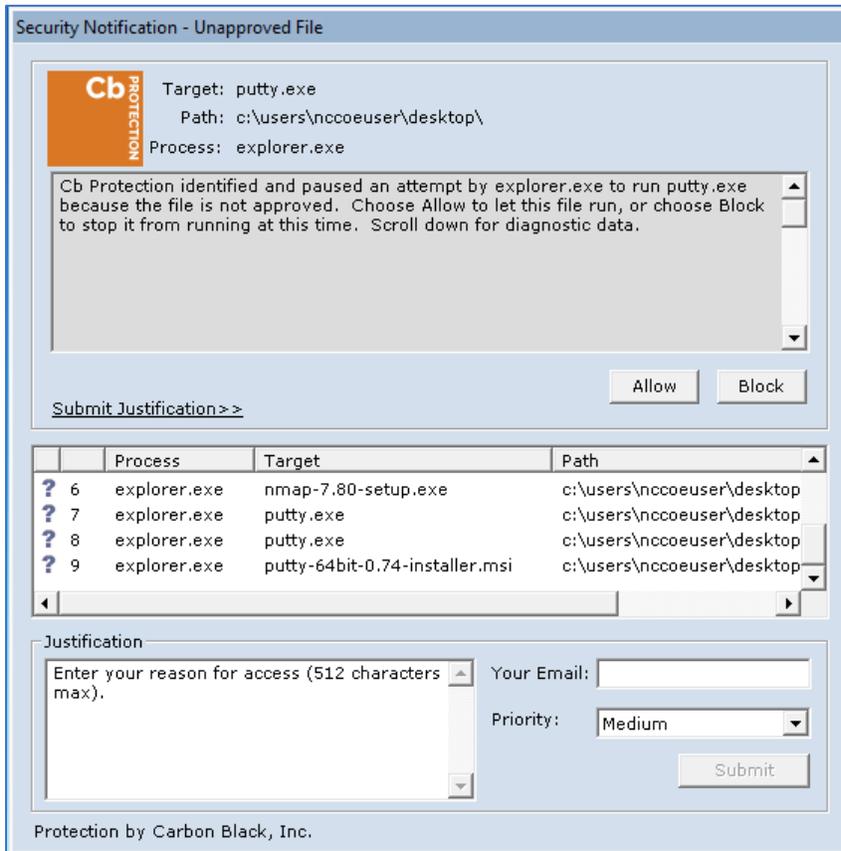
1315 *D.4.1.1 Configuration*

- 1316 ▪ Application Allowlisting: Carbon Black
 - 1317 • Agent installed on systems in the DMZ, Testbed LAN, and PCS VLAN 1 and 2 and configured
 - 1318 to communicate to the Carbon Black Server.
- 1319 ▪ Behavior Anomaly Detection: Tenable.ot
 - 1320 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

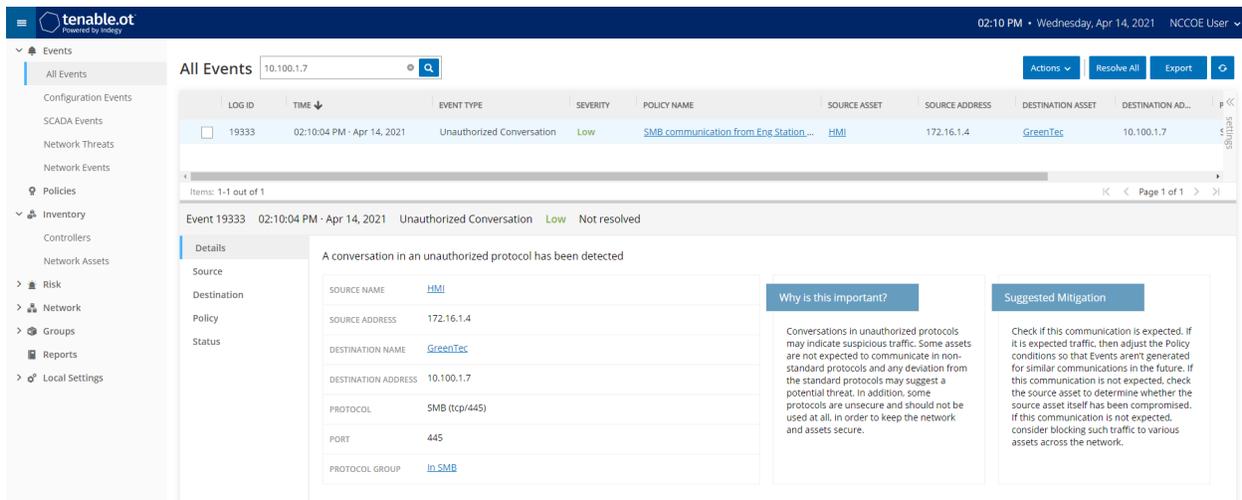
1321 *D.4.1.2 Test Results*

1322 As shown in [Figure D-39](#), Carbon black is able to block and alert on the execution of putty.exe.
1323 Tenable.ot is able to detect the server message block (SMB) connection between an HMI in the Testbed
1324 LAN and the GreenTec server ([Figure D-40](#)). Details of that alert are shown in [Figure D-41](#).

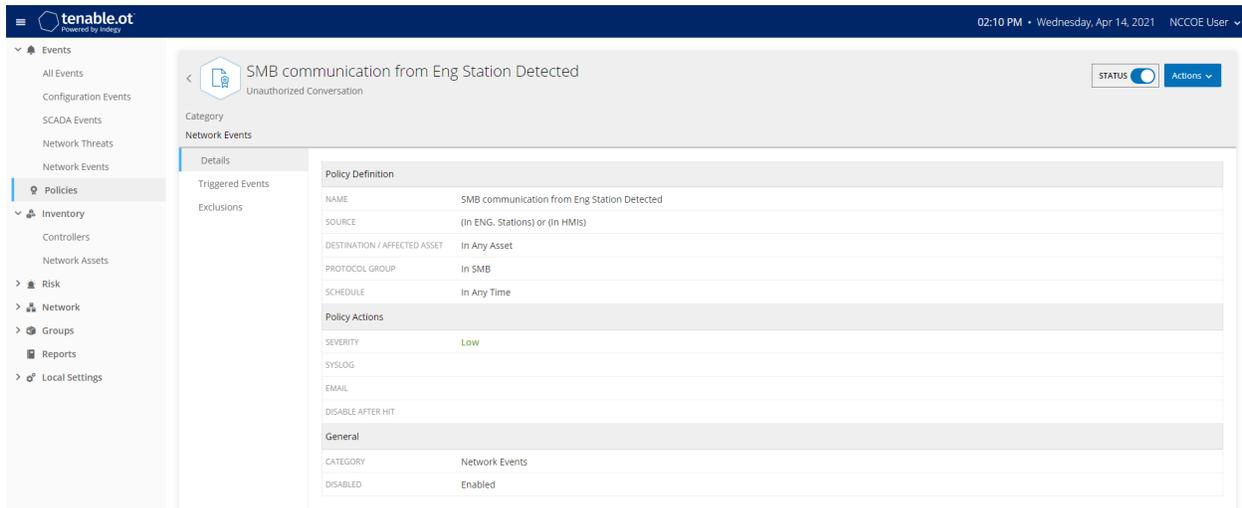
1325 Figure D-39: Carbon Black Blocks the Execution of putty.exe and Other Files



1326 **Figure D-40: Tenable.ot alert Showing the SMB Connection Between the HMI and the GreenTec Server**



1327 **Figure D-41: Tenable.ot Alert Details of the SMB Connection Between the HMI and the network file**
 1328 **system (NFS) Server in the DMZ**



1329 **D.4.2 Build 2**

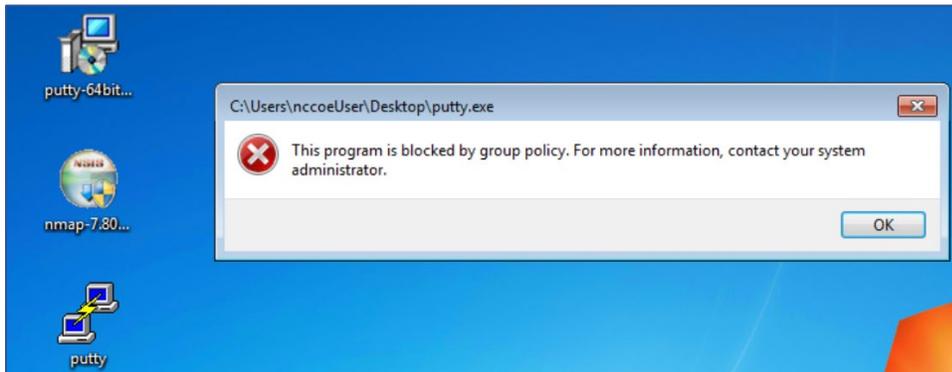
1330 **D.4.2.1 Configuration**

- 1331 **Application Allowlisting: Windows SRP**
- 1332
 - Allowlisting policies are applied to systems in the DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1333
- 1334 **Behavior Anomaly Detection: eyeInspect**
- 1335
 - Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

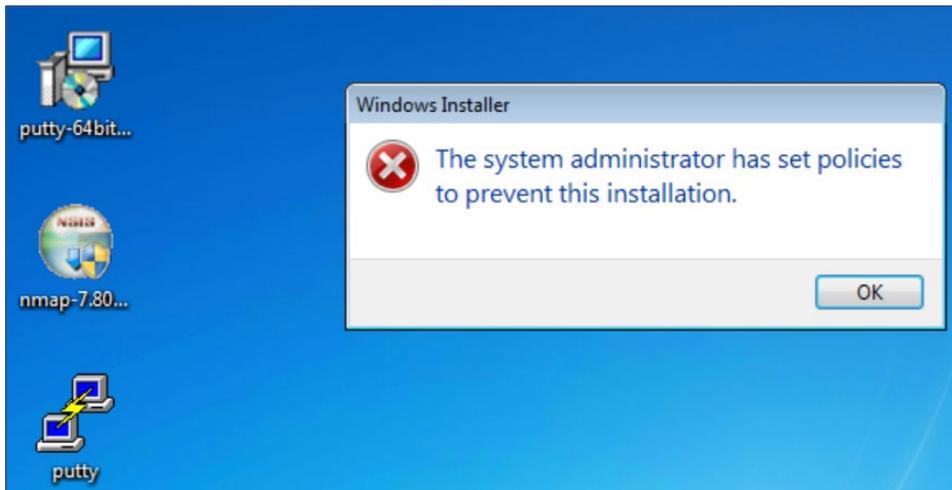
1336 *D.4.2.2 Test Results*

1337 With Windows SRP enabled, putty.exe is not allowed to execute because it is not a permitted
1338 application under group policy, as shown in Figure D-42. Windows SRP also blocks the user’s attempt to
1339 run putty-64bit-0.74-installer.msi. (Figure D-43). Forescout detected the file transfer activity ([Figure D-
1340 44](#)). [Figure D-45](#) shows a detailed description of the alert that was generate for the file transfer activity.

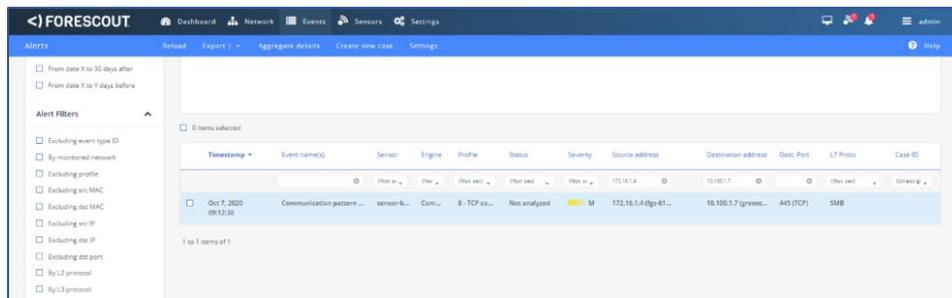
1341 **Figure D-42: Putty.exe is Not Permitted to Run Based on the Windows SRP Configuration**



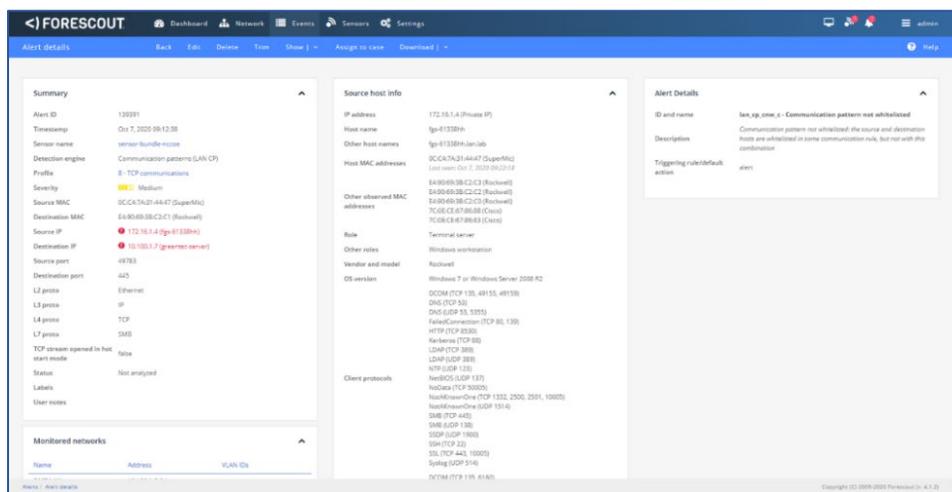
1342 **Figure D-43: putty-64bit-0.74-installer.msi is blocked by Windows SRP**



1343 Figure D-44: Forescout Alert on the File Transfer Activity



1344 Figure D-45: Forescout Alert Details for the File Transfer Activity



1345 D.4.3 Build 3

1346 D.4.3.1 Configuration

1347 Application Allowlisting : Windows SRP

1348 • Settings are applied to systems in the DMZ, Testbed LAN, and Supervisory LAN

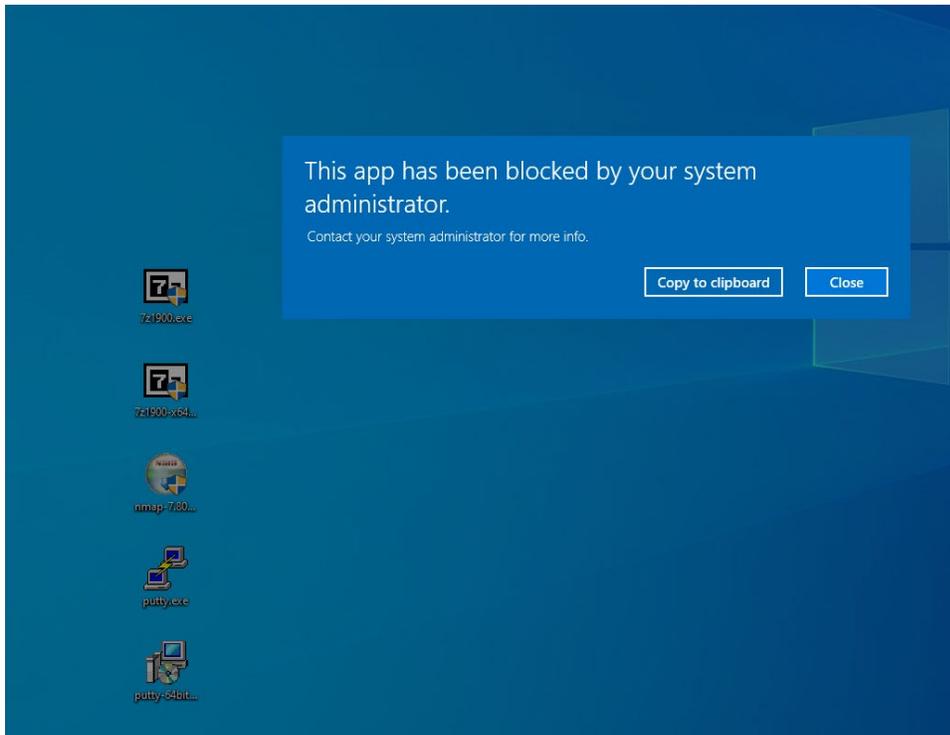
1349 Behavior Anomaly Detection: Dragos

1350 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
1351 Control LAN.

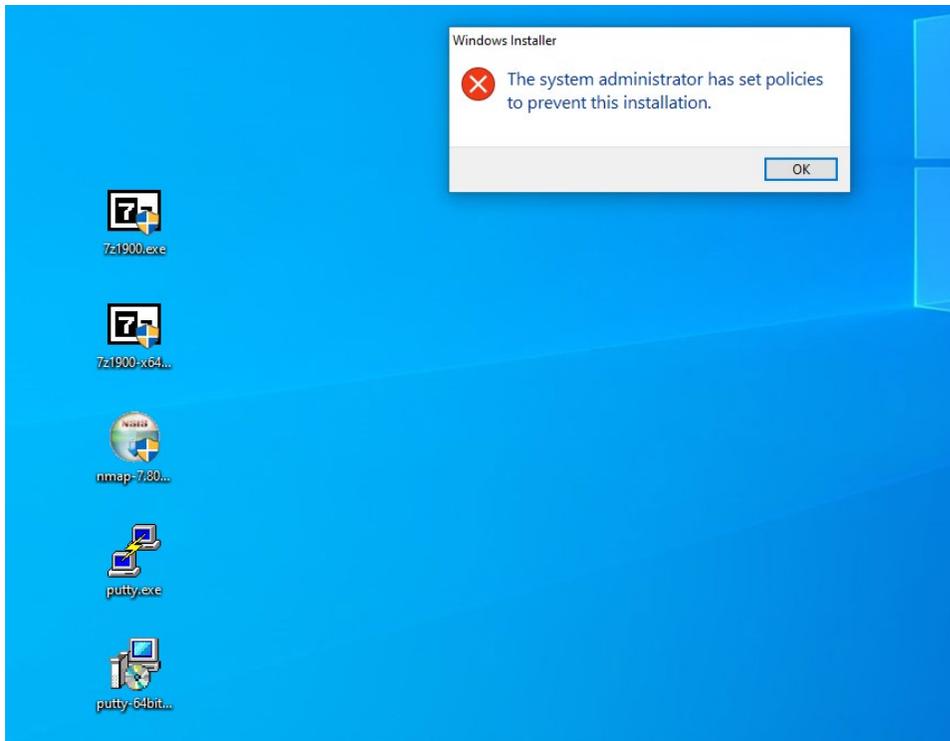
1352 D.4.3.2 Test Results

1353 With Windows SRP enabled, putty.exe is not allowed to execute because it is not a permitted
1354 application under group policy, as shown in [Figure D-46](#). Windows SRP also blocks the user's attempt to
1355 run putty-64bit-0.74-installer.msi ([Figure D-47](#)). Dragos detected the file transfer activity ([Figure D-48](#)).
1356 [Figure D-49](#) shows a detailed description of the alert that was generated for the file transfer activity.

1357 Figure D-46: Putty.exe is Not Permitted to Run Based on the Windows SRP Configuration



1358 Figure D-47: putty-64bit-0.74-installer.msi is Blocked by Windows SRP



1359 Figure D-48: Dragos Alert on the File Transfer Activity

The screenshot displays the Dragos Notification Manager interface. At the top, there are tabs for 'ASSET NOTIFICATIONS', 'SYSTEM ALERTS', and 'RULES'. The 'ASSET NOTIFICATIONS' tab is active, showing a list of alerts. The interface includes a search bar, a refresh button, and a table of notifications. The table columns are: View, Sever., ID, Occurred At, Type, Summary, Message, Detected By, Asset IDs, Source IPv4, Dest. IPv4, and Other IPv4. The alerts are filtered by 'FILE TRANSFER' and show a range from 02/17/21 19:00 UTC to 02/17/21 21:00 UTC. The table contains 28 rows of data, each representing a file transfer alert. The status of each alert is 'VIEW'.

View	Sever.	ID	Occurred At	Type	Summary	Message	Detected By	Asset IDs	Source IPv4	Dest. IPv4	Other IPv4
VIEW	4	148576	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	80, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148574	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148573	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148572	02/17/21 19:42 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 35 downloaded a file with sha256 hash of 0bc...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148571	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 95 downloaded a file with sha256 hash of 0bc...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148570	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148569	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 304...	File Transfer of Suspicious PE	80, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148568	02/17/21 19:42 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 94 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148567	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 304...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148566	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 35 downloaded a file with sha256 hash of aab...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148565	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	80, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148564	02/17/21 19:42 UTC	Communication	A Downloaded file hit on suspicious_raw_sections	Asset 35 downloaded a file with sha256 hash of 0bc...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148563	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 58a...	File Transfer of Suspicious PE	80, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148562	02/17/21 19:49 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 304...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148561	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_sections	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148560	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 94 downloaded a file with sha256 hash of 58a...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148559	02/17/21 19:42 UTC	Communication	A Downloaded file hit on suspicious_raw_sections	Asset 35 downloaded a file with sha256 hash of aab...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148558	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_sections	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	151, 96	10.100.1.7	192.168.0.2...	
VIEW	4	148557	02/17/21 19:43 UTC	Communication	A Downloaded file hit on suspicious_raw_sections	Asset 35 downloaded a file with sha256 hash of 0bc...	File Transfer of Suspicious PE	151, 35	10.100.1.7	192.168.0.20	
VIEW	4	148556	02/17/21 19:42 UTC	Communication	A Downloaded file hit on suspicious_raw_size	Asset 96 downloaded a file with sha256 hash of 436...	File Transfer of Suspicious PE	80, 96	10.100.1.7	192.168.0.2...	

1360 **Figure D-49: Dragos Alert Details of the File Transfer Alert**

DETECTION INFORMATION

WHAT HAPPENED: Asset 95 downloaded a file with sha256 hash of 43d548bba769c35c1584a498f7896c21716646192a0d113e511a00c41ca from 80 which matched the suspicious_raw_size file signature rule.

OCCURRED AT: 02/17/21, 19:43 UTC
LAST SEEN: 01/01/70, 00:00 UTC

COUNT: 1
STATE: UNRESOLVED

DETECTED BY: File Transfer of Suspicious File
SOURCE: 0102059-aaa0-4abc-802a-8ef9e2237f4a

DETECTION QUAD: Threat Behavior
ZONES: DMZ, Cybersecurity LAN

ACTIVITY GROUP: None
ICS CYBER KILLCHAIN STEP: Stage 1 - Delivery

MITRE ATTACK FOR ICS TACTIC: Lateral Movement
MITRE ATTACK FOR ICS TECHNIQUE: T0867: Remote File Copy

QUERY FOCUSED DATASETS: No Associated Open/Resolved Datasets
NOTIFICATION RECORD: None (0 Items)

PLAYBOOKS: No Associated Playbooks
NOTIFICATION COMPONENTS: View (0 Items)

CASES: No Cases Linked

ASSOCIATED ASSETS

View	Type	ID	Name	IP	OS
VIEW	General Use D	80	Asset 80	10.100.1.7	win
VIEW	Router	95	Asset 95	192.168.0.2	dist

COMMUNICATIONS SUMMARY

Protocol	Client	Ephemeral Ports	Server	Server Ports	TX Bytes	RX Bytes
SMTP	10.100.0.20	-	10.100.1.7	-	42.9 KB	42.0 KB
NTLM	10.100.0.20	-	10.100.1.7	-	120.1 KB	121.7 KB
DCE_RPC	10.100.0.20	-	10.100.1.7	-	2.1 MB	65.5 MB

RELATED NOTIFICATIONS

ID	Occurred At	Summary
No Related Notifications.		

1361 **D.4.4 Build 4**1362 **D.4.4.1 Configuration**1363 **Application Allowlisting: Carbon Black**

- Agent installed on systems in the DMZ, Testbed LAN, and Supervisory LAN and configured to communicate to the Carbon Black Server.

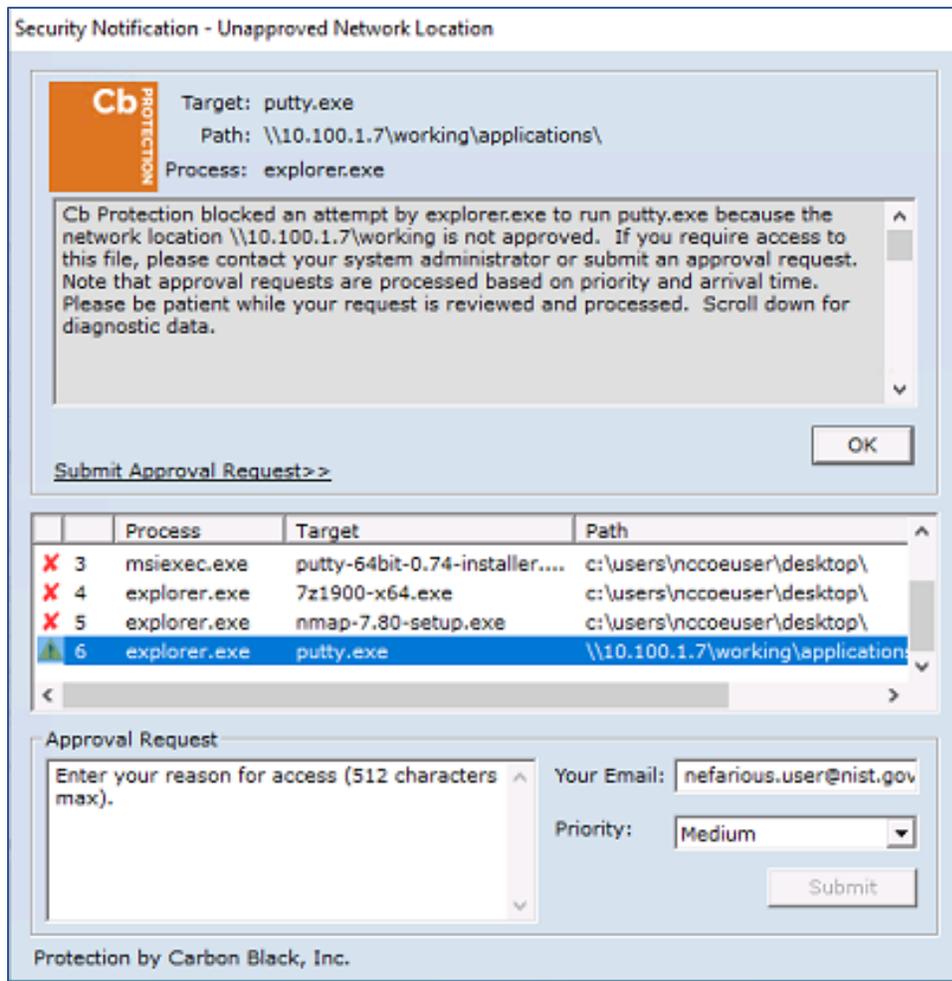
1366 **Behavior Anomaly Detection: Azure Defender for IoT**

- Configured to receive packet streams from DMZ, Testbed LAN and Supervisory LAN, and Control LAN.

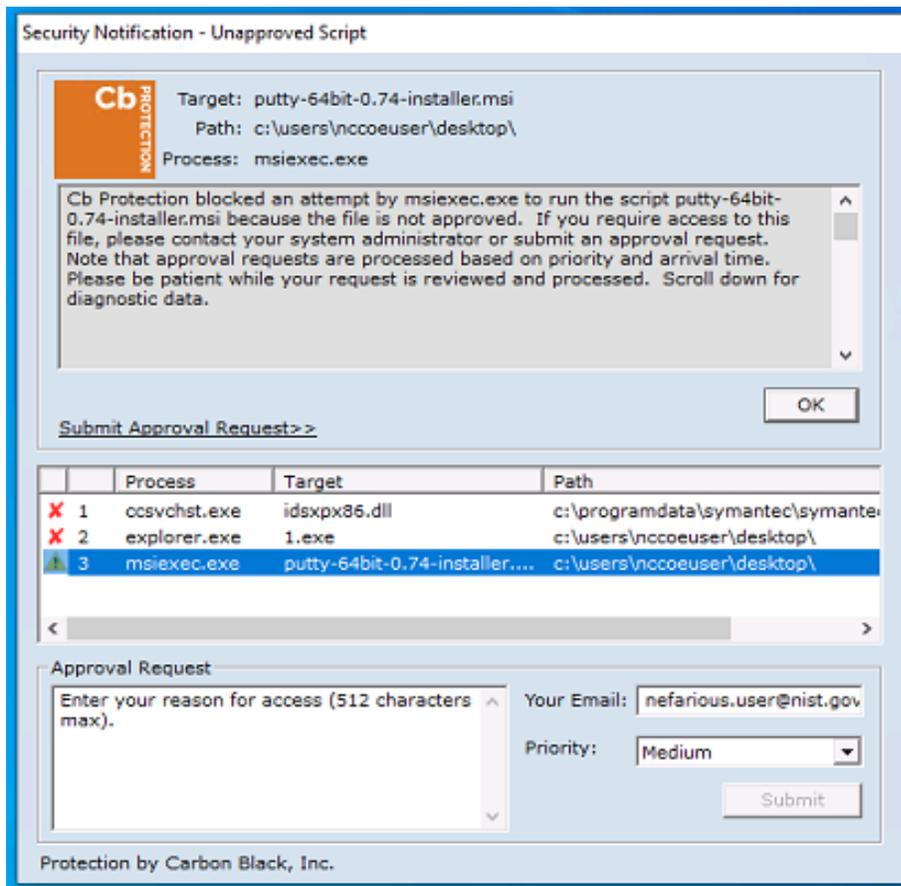
1369 **D.4.4.2 Test Results**

1370 Carbon Black was able to block the execution of putty.exe ([Figure D-50](#)) and the installation of putty-
 1371 64bit-0.74-installer.msi ([Figure D-51](#)). [Figure D-52](#) is the alert dashboard for Azure Defender for IoT that
 1372 shows new activity has been detected. The detailed alert in [Figure D-53](#) provides details of an RPC
 1373 connection between the GreenTec server and the Testbed LAN. A timeline of events showing a file
 1374 transfer has occurred is shown in [Figure D-54](#).

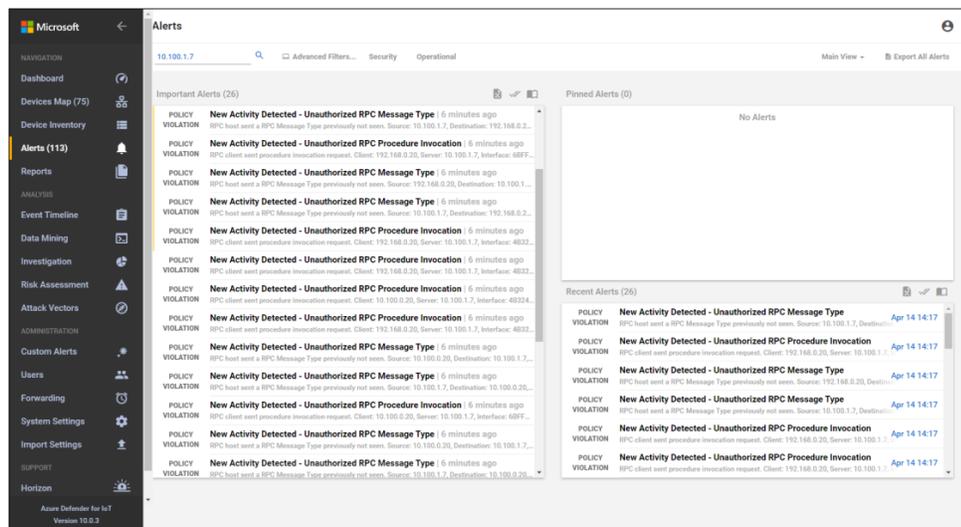
1375 Figure D-50: Carbon Black Alert Showing that putty.exe is Blocked from Executing



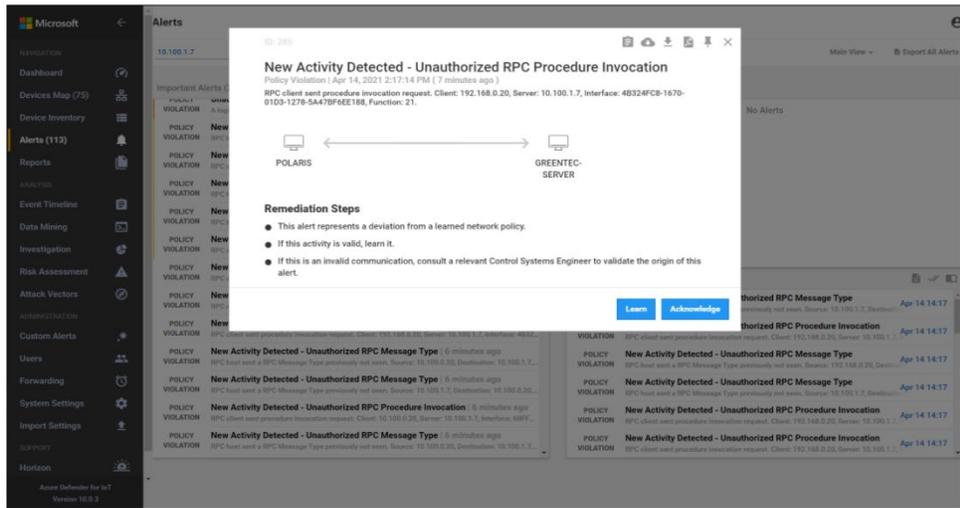
1376 Figure D-51: Carbon Black Alert Showing the Execution of putty-64bit-0.74-installer.msi Being Blocked



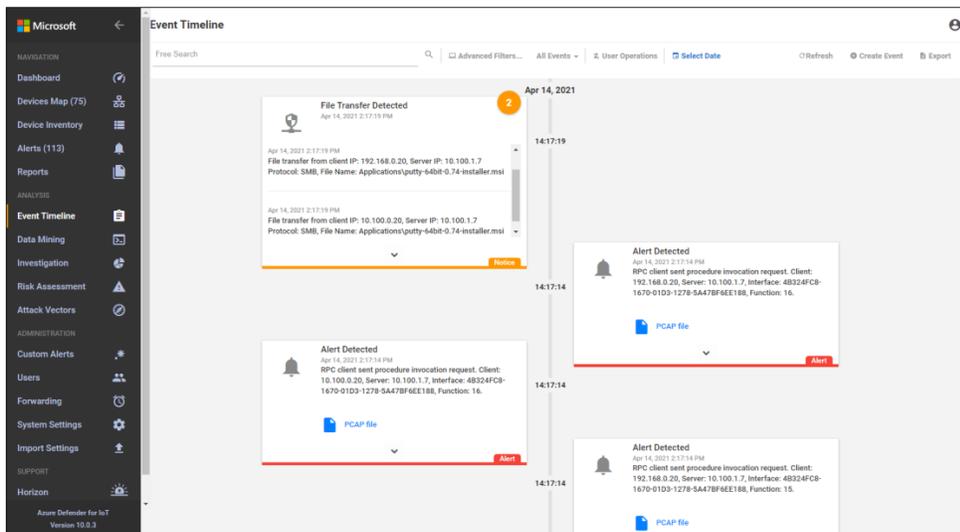
1377 Figure D-52: Azure Defender for IoT Alert Dashboard Showing Detection of a New Activity



1378 Figure D-53: Azure Defender for IoT Alert Details Showing RPC Connection Between the DMZ and the
 1379 Testbed LAN



1380 Figure D-54: Azure Defender for IoT Event Alert Timeline Showing the File Transfer



1381 **D.5 Executing Scenario 5: Protect from Unauthorized Addition of a Device**

1382 An authorized individual with physical access connects an unauthorized device on the manufacturing
 1383 network and then uses it to connect to devices and scan the network. The expected result is behavioral
 1384 anomaly detection identifies the unauthorized device.

1385 **D.5.1 Build 1**

1386 *D.5.1.1 Configuration*

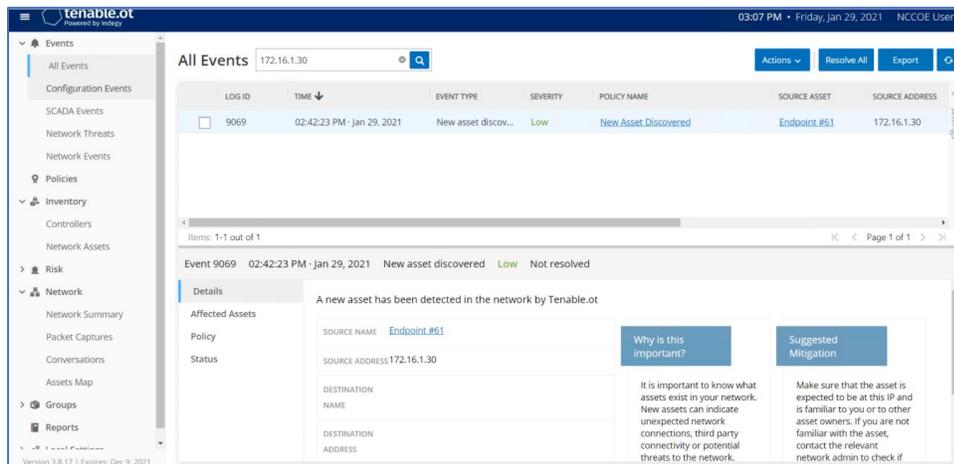
1387 ▪ Behavior Anomaly Detection: Tenable.ot

- 1388 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

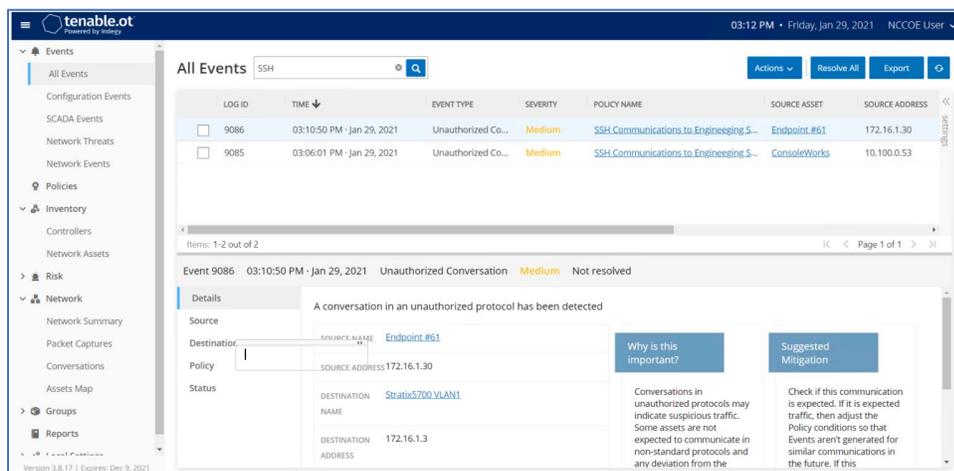
1389 *D.5.1.2 Test Results*

1390 Tenable.ot detects and alerts on the addition of a device to the environment. [Figure D-55](#) shows an
1391 event reported by Tenable.ot when a device was connected to the wireless access point in the
1392 manufacturing environment. Tenable.ot also detects other activity from the device, as shown in [Figure](#)
1393 [D-56](#), in which the new device tries to establish a secure shell (SSH) connection to the network switch.

1394 Figure D-55: Tenable.ot Event Showing a New Asset has Been Discovered



1395 Figure D-56: Tenable.ot Event Showing Unauthorized SSH Activities



1396 D.5.2 Build 2

1397 D.5.2.1 Configuration

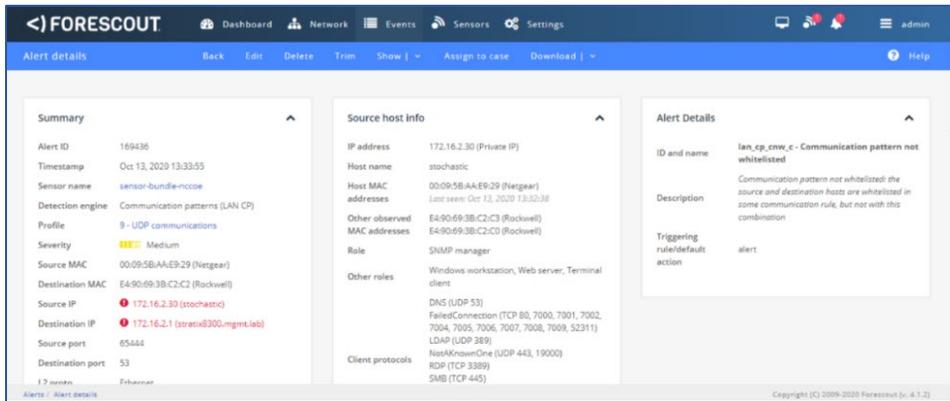
1398 ■ Behavior Anomaly Detection: eyeInspect

- 1399 ● Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

1400 D.5.2.2 Test Results

1401 Forescout detects when an unauthorized device connects to a wireless access point in the
 1402 manufacturing environment. [Figure D-57](#) shows that Forescout raises an alert on the DNS request from
 1403 the wireless access point to the gateway. The device establishes an SSH connection, which is detected by
 1404 Forescout as shown in [Figure D-58](#). A more detailed view of the alert is shown in [Figure D-59](#).

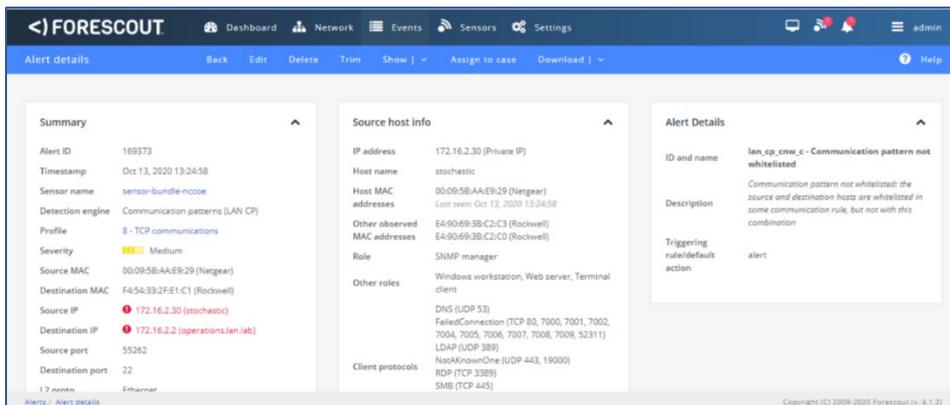
1405 Figure D-57: Forescout Alert on the DNS Request from the New Device



1406 Figure D-58: Forescout alert showing the SSH connection



1407 Figure D-59: Detailed Forescout alert of the Unauthorized SSH Connection



1408 D.5.3 Build 3

1409 D.5.3.1 Configuration

- 1410 ■ Behavior Anomaly Detection: Dragos
 - 1411 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1412 Control LAN.

1413 *D.5.3.2 Test Results*

1414 Dragos detected the traffic generated by the new asset and generated several alerts as seen in the list of
1415 alerts in [Figure D-60](#). Details of different aspects of the network scanning can be seen in [Figure D-61](#) and
1416 [Figure D-62](#). Details on the new device can also be seen in [Figure D-63](#).

DRAFT

1417 Figure D-60: Dragos Dashboard Showing Alerts Generated upon Detecting New Device and Network
1418 Scanning

The screenshot shows the 'Notification Manager' interface. At the top, there are tabs for 'ASSET NOTIFICATIONS', 'SYSTEM ALERTS', and 'RULES'. The 'ASSET NOTIFICATIONS' tab is active, displaying a table of alerts. The table has columns for 'View', 'Server', 'ID', 'Occurred At', 'Type', 'Summary', 'Message', 'Detected By', 'Asset IDs', 'Source IPv4', 'Dest. IPv4', and 'Other IPv4'. The alerts listed include:

- Asset 2709: NewSourceCidr Detected
- Asset 2789: NewSourceEthernetAddressDetection
- Asset 2789: NewDestinationEthernetAddressDetection
- Asset 2791: NewCommunicationPairing
- Asset 102: NewCommunicationPairing
- Asset 85: ICMP Sweep Detected

At the bottom of the table, it says 'Showing 1 to 5 of 5 Notifications'. On the right side, there are navigation buttons: 'FIRST', 'PREVIOUS', '1', 'NEXT', 'LAST'.

1419 Figure D-61: Details of Network Scanning Activity

The screenshot shows the details for an 'ICMP Scan Detected' alert. The main section is 'DETECTION INFORMATION'. It includes a 'WHAT HAPPENED:' section with a detailed description of the scan activity, mentioning '1070 lines out of 1070 (100.00%)' and '1 (0.70%)' of contiguous addresses were detected. Below this, there are sections for 'OCCURRED AT:', 'COUNT:', 'DETECTED BY:', 'DETECTION QUAD:', 'ACTIVITY GROUP:', 'MITRE ATTACK FOR ICS TACTIC:', 'QUERY-FOCUSED DATASETS:', 'PLAYBOOKS:', and 'CASES:'. To the right, there is an 'ASSOCIATED ASSETS' section showing 'Asset 85' and a 'COMMUNICATIONS SUMMARY' section which is currently empty. At the bottom right, there are buttons for 'CREATE A RULE', 'CREATE CASE', and 'NEXT'.

1422 D.5.4 Build 4

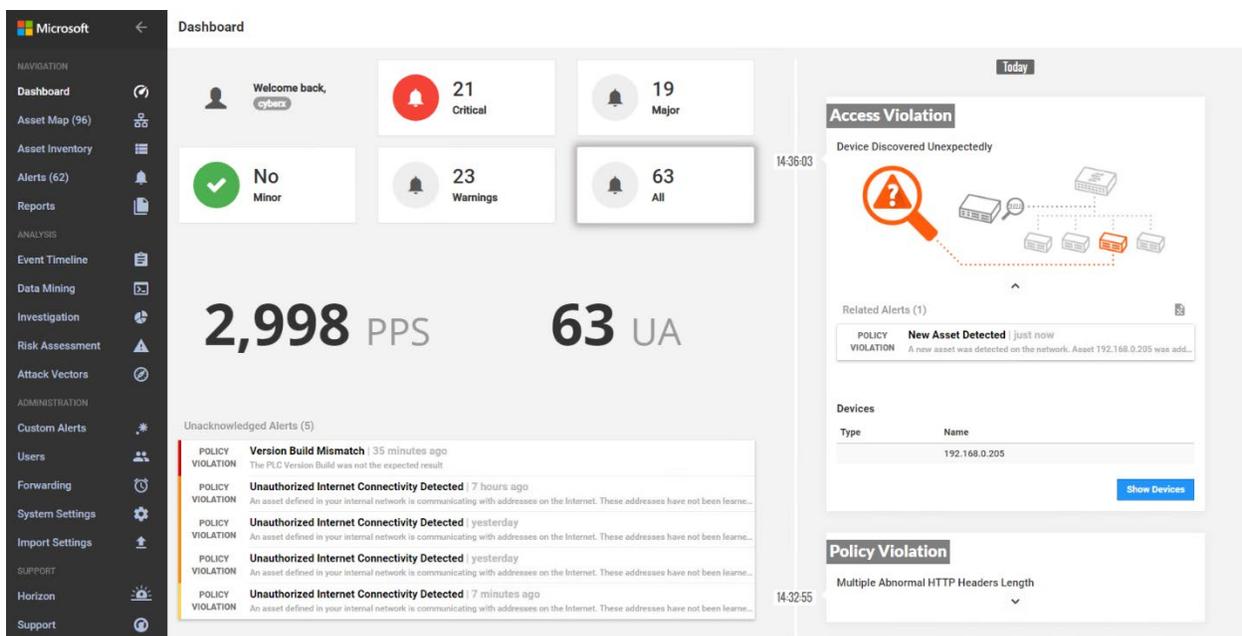
1423 D.5.4.1 Configuration

- 1424 Behavior Anomaly Detection: Azure Defender for IoT
 - 1425 Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1426 Control LAN.

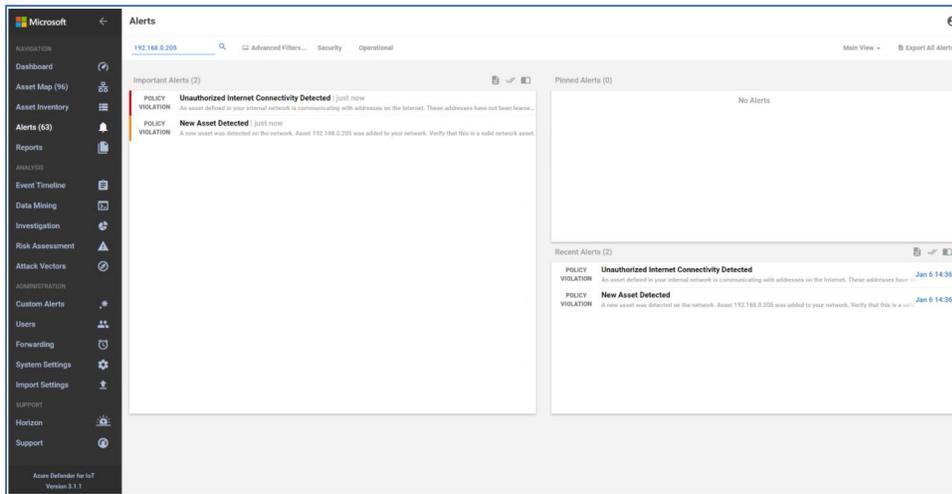
1427 D.5.4.2 Test Results

1428 A “New Asset Detected” alert is shown on Azure Defender for IoT dashboard (Figure D-64) and on the
1429 Alert screen (Figure D-65). Figure D-66 shows the alert management options in Azure Defender for IoT.
1430 The details of the network scanning alert are shown in Figure D-67.

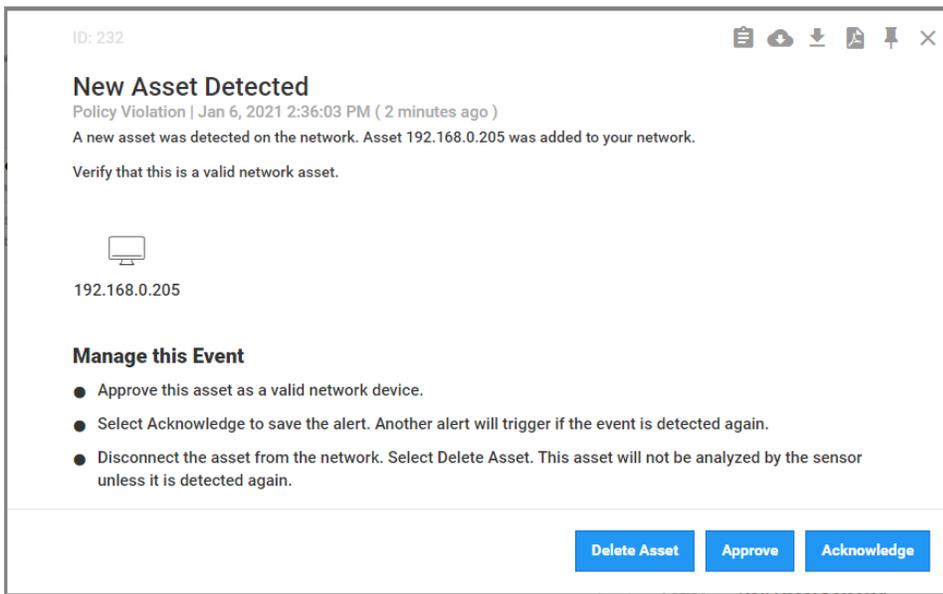
1431 Figure D-64: Azure Defender for IoT Dashboard Showing the Alerts, Including for the New Asset



1432 Figure D-65: Azure Defender for IoT Detects New Asset in the Environment



1433 Figure D-66: Azure Defender for IoT Alert Management Options



1434 **Figure D-67: Details for Network Scanning Alert**

Device Connection Detected
Jan 6, 2021 2:36:03 PM

Grouped Events

Jan 6, 2021 2:36:03 PM
Connected devices 192.168.1.103 and 192.168.0.205

Jan 6, 2021 2:36:03 PM
Connected devices 192.168.0.205 and 192.168.1.101

Jan 6, 2021 2:36:03 PM
Connected devices 192.168.0.205 and 10.100.0.17

Assets

Type	Name
	Station 2
	LAN-AD
	Station 4
	Station 3
	Station 1
	CRS Supervisory LAN Gateway
	192.168.0.205

Info

1435 **D.6 Executing Scenario 6: Detect Unauthorized Device-to-Device**

1436 **Communications**

1437 An authorized device that is installed on the network attempts to establish an unapproved connection
 1438 not recorded in the baseline. The expected result is the behavioral anomaly detection products alert on
 1439 the non-baseline network traffic.

1440 **D.6.1 Build 1**

1441 *D.6.1.1 Configuration*

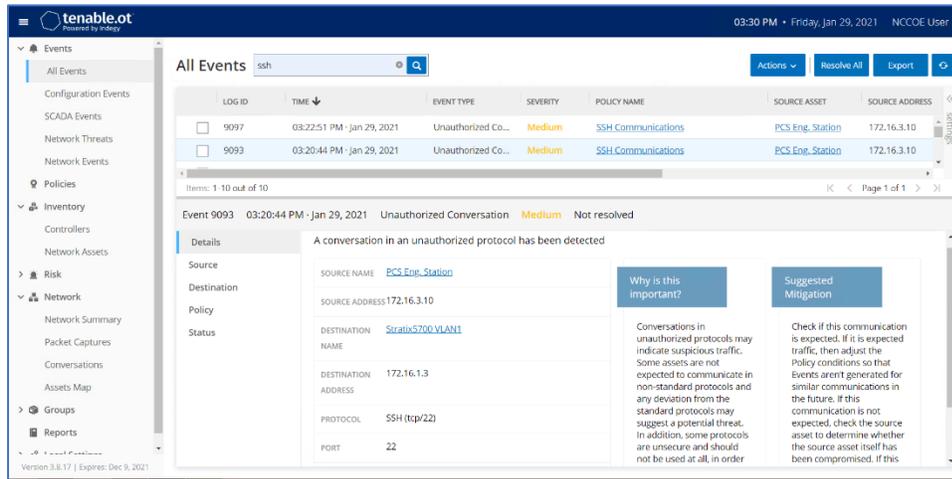
- 1442 ▪ Behavior Anomaly Detection: Tenable.ot
- 1443 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

DRAFT

1444 *D.6.1.2 Test Results*

1445 The unapproved SSH traffic is detected by Tenable.ot as shown in Figure D-68.

1446 **Figure D-68: Tenable.ot Event Log Showing the Unapproved SSH Traffic**



1447 *D.6.2 Build 2*

1448 *D.6.2.1 Configuration*

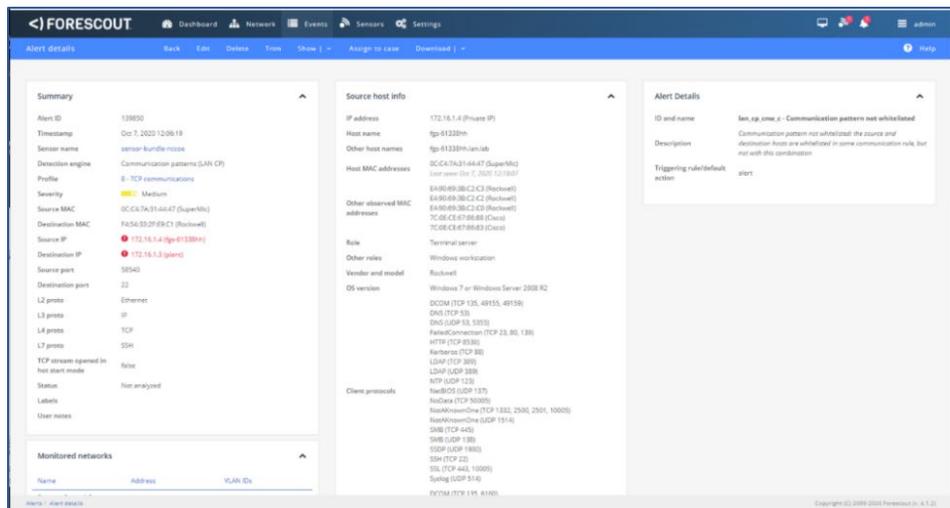
- 1449 ▪ Behavior Anomaly Detection: eyeInspect
- 1450 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.

1451 *D.6.2.2 Test Results*

1452 SSH communication from HMI computer to the network switch is not defined in the baseline; Forescout

1453 flags this communication as shown in [Figure D-69](#).

1454 Figure D-69: Forescout Alert Showing the Unapproved SSH Traffic



1455 D.6.3 Build 3

1456 D.6.3.1 Configuration

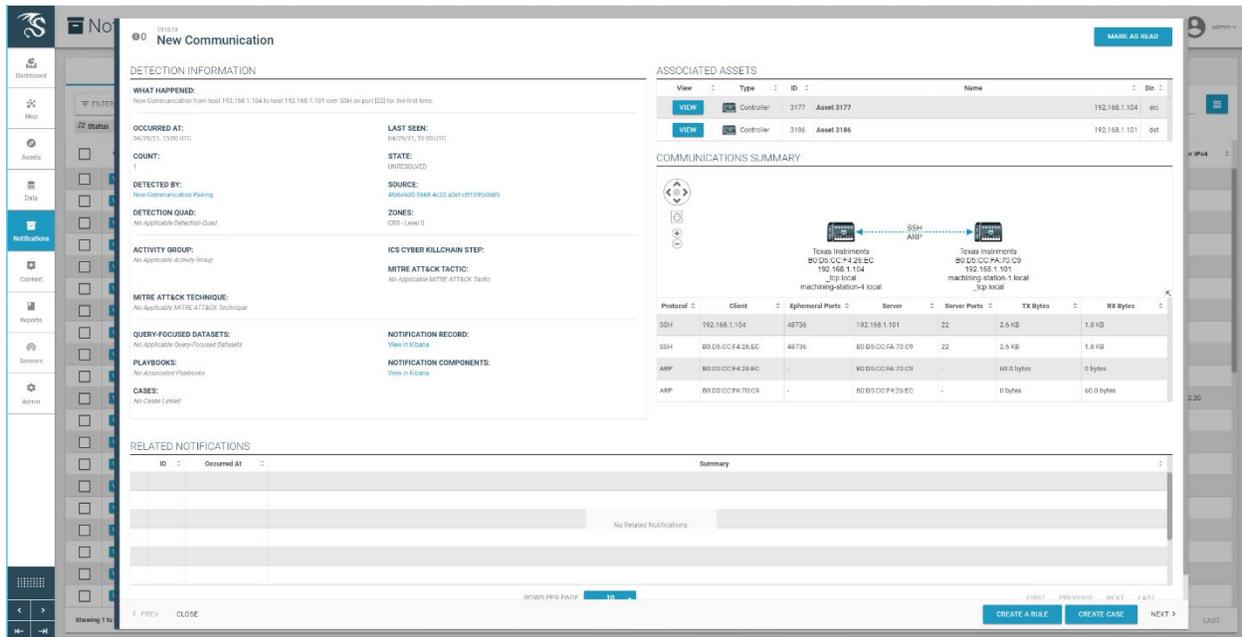
1457 Behavior Anomaly Detection: Dragos

- 1458 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
- 1459 Control LAN.

1460 D.6.3.2 Test Results

1461 Dragos detected the non-baseline SSH traffic as shown in [Figure D-70](#).

1462 **Figure D-70: Dragos Alert Showing the Unapproved SSH Connection Between Devices**



1463 **D.6.4 Build 4**

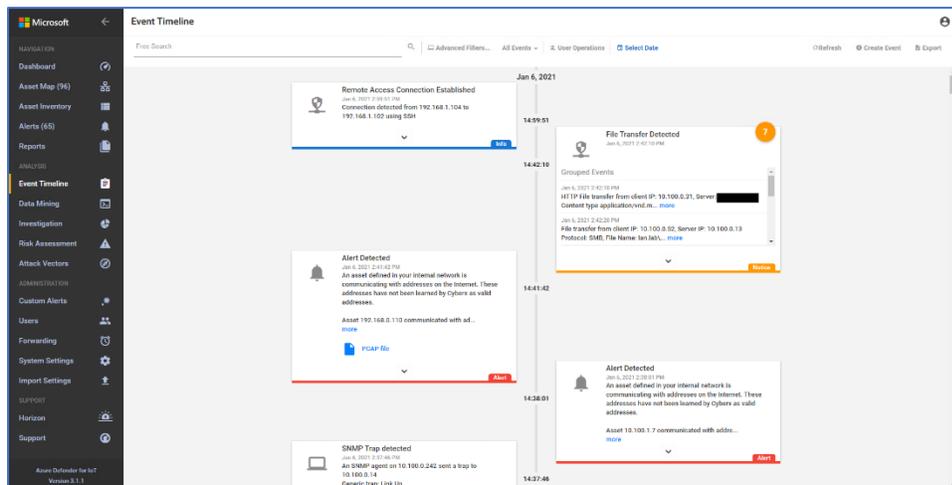
1464 **D.6.4.1 Configuration**

- 1465 ■ Behavior Anomaly Detection: Azure Defender for IoT
- 1466 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
- 1467 Control LAN.

1468 **D.6.4.2 Test Results**

1469 A device attempts to establish a remote access connection via SSH. Azure Defender for IoT was able to

1470 detect this activity as shown in [Figure D-71](#).

1471 **Figure D-71: Azure Defender for IoT Event Identified the Unauthorized SSH Connection**1472 **D.7 Executing Scenario 7: Protect from Unauthorized Deletion of Files**

1473 An authorized user attempts to delete files on an engineering workstation and a shared network drive
 1474 within the manufacturing system. The expected result is the file integrity checking tools in the
 1475 environment alert on the deletion or prevent deletion entirely.

1476 **D.7.1 Build 1**1477 **D.7.1.1 Configuration**

- 1478
- 1479 ■ File Integrity Checking: Carbon Black
 - 1480 • Agent installed on workstations and configured to communicate to the Carbon Black Server.
 - 1481 ■ File Integrity Checking: WORMdisk
 - 1482 • Network file share on server is configured to use WORMdisk.

1483 **D.7.1.2 Test Results**

1484 Carbon Black reports file deleting activities as shown in [Figure D-72](#). GreenTec protects the files on its
 1485 drive from being deleted.

1486 **Figure D-72 Event Messages from Carbon Black Showing File Deletion Attempts**

Timestamp	Se...	Type	Subtype	Source	Description	IP Address	User	Process Name
Feb 3 2021 01:35:55 PM	Info	Policy Enforcement	Report write (Custom Rule)	LAN\FGS-47631EHH	'c:\users\administrator\downloads\va\nccoe_test_file.txt' was deleted by FGS-47631EHH\Administrator.	172.16.3.10	FGS-47631EHH\Admini...	explorer.exe
Feb 3 2021 01:35:50 PM	Info	Policy Enforcement	Report write (Custom Rule)	LAN\FGS-47631EHH	'c:\users\administrator\downloads\va\testscenario\nccoe_test_file.txt' was deleted by FGS-47631EHH\Administrator.	172.16.3.10	FGS-47631EHH\Admini...	explorer.exe
Feb 3 2021 01:35:35 PM	Info	Policy Enforcement	Report write (Custom Rule)	LAN\FGS-47631EHH	'c:\users\administrator\documents\tesim\nccoe_test_file.txt' was deleted by FGS-47631EHH\Administrator.	172.16.3.10	FGS-47631EHH\Admini...	explorer.exe

1487 **D.7.2 Build 2**1488 **D.7.2.1 Configuration**1489 **File Integrity Checking: Security Onion**

- 1490 **• The agent is installed on workstations and configured to communicate to the Security**
- 1491 **Onion Server.**

1492 **File Integrity Checking: WORMdisk**

- 1493 **• Network file share on server is configured to use WORMdisk.**

1494 **D.7.2.2 Test Results**

1495 Security Onion Wazuh alerts on file deletion as shown in [Figure D-73](#). Files stored on a storage drive
 1496 protected by GreenTec are protected from deletion.

1497 Figure D-73: Security Onion Wazuh Alert Showing a File Has Been Deleted

@timestamp	Q Q [] *	October 15th 2020, 13:05:33.753
t @version	Q Q [] *	1
t _id	Q Q [] *	JXY5LXUB1YHtrLLyWhik
t _index	Q Q [] *	seconion:logstash-ossec-2020.10.15
# _score	Q Q [] *	-
t _type	Q Q [] *	doc
t agent.id	Q Q [] *	005
? agent.ip	Q Q [] *	▲ 172.16.3.10
t agent.name	Q Q [] *	PCS-EWS
# alert_level	Q Q [] *	7
t classification	Q Q [] *	"Bad word" matching
t decoder.name	Q Q [] *	syscheck_integrity_changed
t description	Q Q [] *	File deleted.
t event_type	Q Q [] *	ossec
t full_log	Q Q [] *	File 'c:\users\administrator\downloads\ra\testscenarios\test_file.txt' was deleted. (Audit) User: 'Administrator (S-1-5-21-239850103-4004920075-3296975006-500)' (Audit) Process id: '6056' (Audit) Process name: 'C:\Windows\explorer.exe'
t host	Q Q [] *	gateway
t id	Q Q [] *	1602781532.2062049
t location	Q Q [] *	syscheck
# logstash_time	Q Q [] *	0.002

1498

D.7.3 Build 3

1499

D.7.3.1 Configuration

- 1500
- 1501 ▪ File Integrity Checking: Security Onion
 - 1502 • Agent installed on workstations and configured to communicate to the Security Onion Server.
 - 1503 ▪ File Integrity Checking: WORMdisk
 - 1504 • Network file share on server is configured to use WORMdisk.

1505

D.7.3.2 Test Results

1506 Security Onion Wazuh detected the deletion of the files as shown in the Security Onion Server log in
1507 [Figure D-74](#). Files stored on a storage drive protected by GreenTec are protected from deletion.

1508 **Figure D-74: Alert from Security Onion for a File Deletion**

Field	Value
@timestamp	Feb 12, 2021 @ 10:41:45.583
@version	1
_id	NHrn1ncblvRAGpavc9g
_index	seconion:logstash-oesec-2021_02_12
_score	-
_type	_doc
agent.id	003
agent.ip	192.168.0.20
agent.name	CRS-EMS
alert.level	7
classification	"Bad word" matching
decoder.name	syscheck_integrity_changed
description	File deleted.
event.type	syscheck
full.log	File 'c:\users\nccooser\documents\twincat projects\crs workcell\boot\twincat ce7 (arm7)\pic\port_051.0ce' was deleted.
host	gateway
id	1613144504.13813845
location	syscheck
logstash.time	0.007
manager.name	seconion
message	>
port	36884
syscheck.event	deleted
syscheck.path	c:\users\nccooser\documents\twincat projects\crs workcell\boot\twincat ce7 (arm7)\pic\port_051.0ce

1509 **D.7.4 Build 4**1510 **D.7.4.1 Configuration**

- 1511 ■ File Integrity Checking: Carbon Black
 - 1512 ● Agent installed on workstations and configured to communicate to the Carbon Black
 - 1513 Server.
- 1514 ■ File Integrity Checking: WORMdisk
 - 1515 ● Network file share on server is configured to use WORMdisk.

1516 **D.7.4.2 Test Results**

1517 The attempts to delete a file are detected by Carbon Black as shown in [Figure D-75](#). Files stored on a
 1518 storage drive protected by GreenTec are protected from deletion.

1519 **Figure D-75: Carbon Black Alerts Showing That a File Has Been Deleted**

Timestamp	Severit...	Type	Subtype	Source	Description	IP Address	User	Process Name
Jan 6 2021 02:25:56 PM	Notice	Computer Manage...	Agent deleted events	WORKGROUP\eee...	Computer 'WORKGROUP\eee93e4e44od-vm' deleted 508 events.	10.100.1.61		
Jan 6 2021 02:24:14 PM	Info	Policy Enforcement	Report write (Custom Rule)	WORKGROUP\eee...	'c:\users\guest-user\documents\tcxaeshell\crs workcell\untitled2_old_v1\myp3j\untitled2.splcproj' was deleted by 'eee93e4e44od-vm\guest-user'.	10.100.1.61	eee93e4e44od-vm\guest-user	explorer.exe
Jan 6 2021 02:24:14 PM	Info	Policy Enforcement	Report write (Custom Rule)	WORKGROUP\eee...	'c:\users\guest-user\documents\tcxaeshell\crs workcell\untitled2_old_v1\myp3j\untitled2.splcproj' was deleted by 'eee93e4e44od-vm\guest-user'.	10.100.1.61	eee93e4e44od-vm\guest-user	explorer.exe
Jan 6 2021 02:24:14 PM	Info	Policy Enforcement	Report write (Custom Rule)	WORKGROUP\eee...	'c:\users\guest-user\documents\tcxaeshell\crs workcell\untitled2_old_v1\myp3j\untitled2.splcproj' was deleted by 'eee93e4e44od-vm\guest-user'.	10.100.1.61	eee93e4e44od-vm\guest-user	explorer.exe
Jan 6 2021 02:24:14 PM	Info	Policy Enforcement	Report write (Custom Rule)	WORKGROUP\eee...	'c:\users\guest-user\documents\tcxaeshell\crs workcell\untitled2\twinsafegroup1\alias devices\term 4 (el2904) - module 1 (fsoes).sds' was deleted by 'eee93e4e44od-vm\guest-user'.	10.100.1.61	eee93e4e44od-vm\guest-user	explorer.exe
Jan 6 2021 02:24:14 PM	Info	Policy Enforcement	Report write (Custom Rule)	WORKGROUP\eee...	'c:\users\guest-user\documents\tcxaeshell\crs workcell\untitled2\twinsafegroup1\alias devices' was deleted by 'eee93e4e44od-vm\guest-user'.	10.100.1.61	eee93e4e44od-vm\guest-user	explorer.exe

1520 **D.8 Executing Scenario 8: Detect Unauthorized Modification of PLC Logic**

1521 An authorized user performs an unapproved or unauthorized modification of the PLC logic through the
 1522 secure remote access tools. The expected result is the behavioral anomaly detection tools will detect
 1523 and capture the activity, flagging it for review.

1524 The behavior anomaly detection tools can detect program downloads to the PLC. Program download
 1525 detection needs to be correlated with the maintenance management system to determine if the
 1526 download was authorized and approved. This was not demonstrated as part of this scenario.

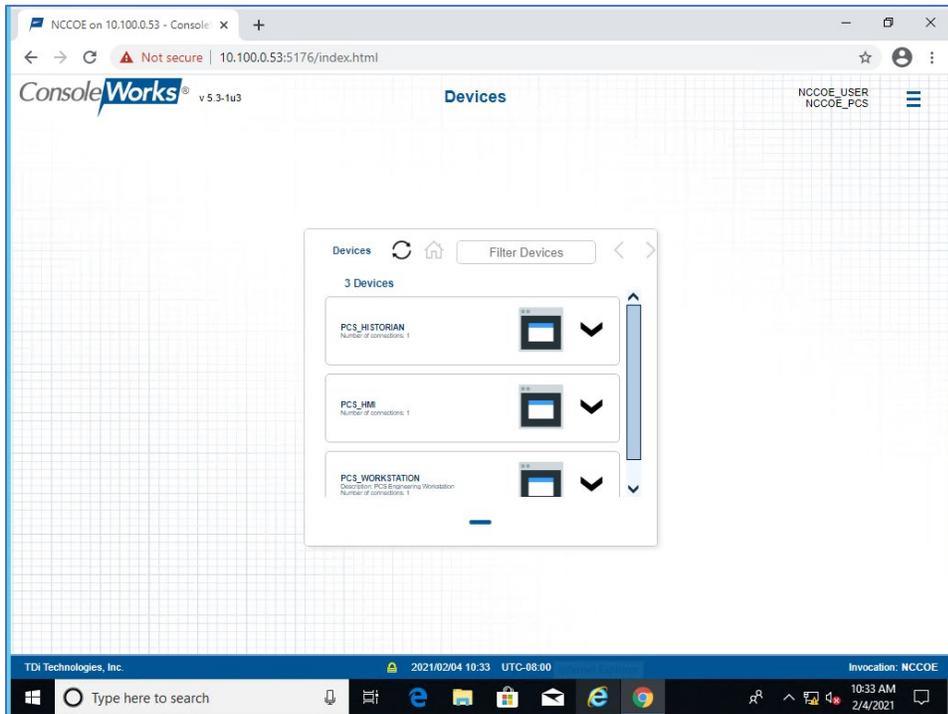
1527 **D.8.1 Build 1**1528 **D.8.1.1 Configuration**

- 1529 ■ Behavior Anomaly Detection: Tenable.ot
 - 1530 ● Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1531 ■ Remote Access: Cisco VPN
 - 1532 ● Configured to allow authorized VPN users to access to ConsoleWorks web interface.
- 1533 ■ User Authentication/User Authorization: ConsoleWorks
 - 1534 ● Configured for accessing the PCS environment

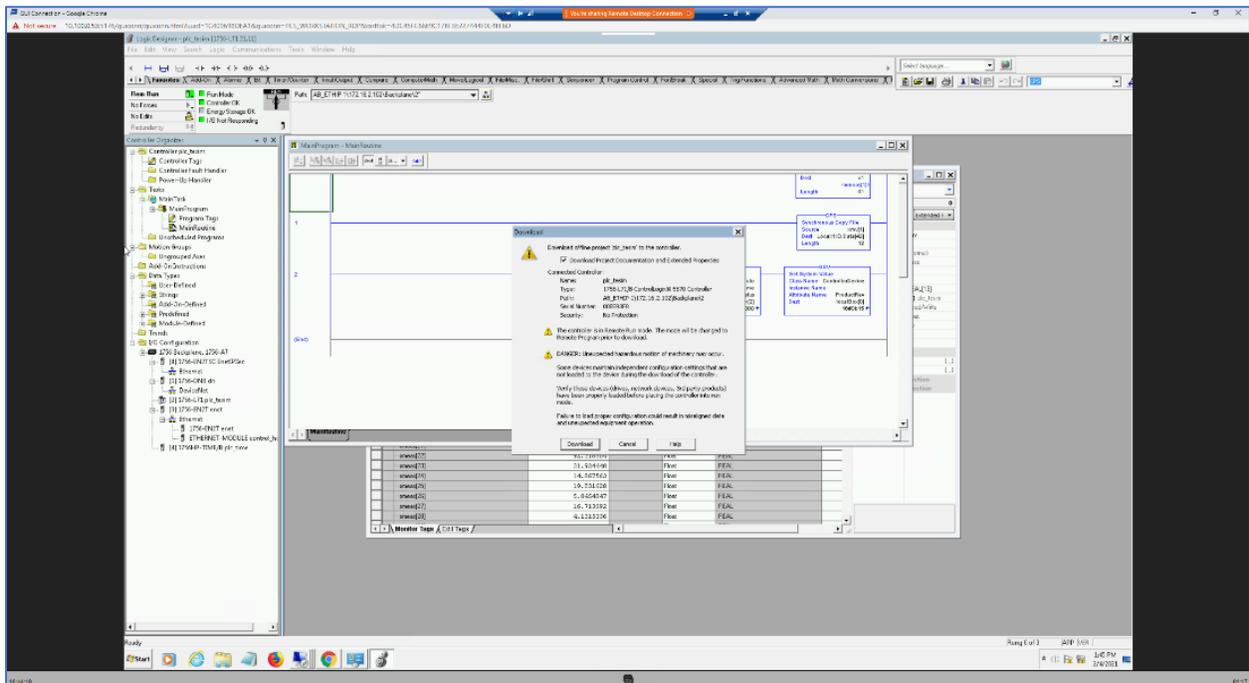
1535 **D.8.1.2 Test Results**

1536 In this build, a remote session Studio 5000 Logix Designer is established to perform PLC file operations as
 1537 shown in [Figure D-76](#) and [Figure D-77](#). Tenable.ot is able to detect the PLC file modifications as shown in
 1538 [Figure D-78](#) with details shown in [Figure D-79](#) and [Figure D-80](#).

1539 Figure D-76: Remote Access to Systems in PCS Network is Being Established Through ConsoleWorks



1540 Figure D-77: Remote Session into Studio 5000 to Perform PLC File Operations



1541 Figure D-78: Tenable.ot Detected the Transfer of PLC Logic File to the Rockwell PLC

LOG ID	TIME ↓	EVENT TYPE	SEVERITY	POLICY NAME
<input type="checkbox"/> 12416	01:47:47 PM · Feb 4, 2021	Change in Key Sw...	High	Change in controller key state
<input type="checkbox"/> 12414	01:46:52 PM · Feb 4, 2021	Rockwell PLC Start	Low	Rockwell PLC Start
<input type="checkbox"/> 12413	01:46:30 PM · Feb 4, 2021	Rockwell Code Do...	Medium	Rockwell Code Download
<input type="checkbox"/> 12412	01:46:27 PM · Feb 4, 2021	Rockwell PLC Stop	High	Rockwell PLC Stop
<input type="checkbox"/> 12410	01:45:05 PM · Feb 4, 2021	Rockwell Go Online	Low	Rockwell Online Session
<input type="checkbox"/> 12409	01:44:38 PM · Feb 4, 2021	RDP Connection (...)	Medium	RDP Communication to an Engineerin...

1542 Figure D-79: Tenable.ot PLC Stop alert details

Rockwell PLC Stop
Rockwell PLC Stop

Category: Configuration Events

Items: 1-1 out of 1

Event 12412 01:46:27 PM · Feb 4, 2021 Rockwell PLC Stop High Not resolved

Details

The controller state was changed to Stop

Source	SOURCE PCS Eng. Station	NAME
Destination	SOURCE 172.16.3.10	
Policy	DESTINATION plc_tesim	NAME
Status	DESTINATION 172.16.2.102	

Why is this important?
The system detected a change in the controller state that was made

Suggested Mitigation
1) Check whether the state change was made as part of scheduled maintenance work and

1543 **Figure D-80: Tenable.ot PLC Program Download Alert Details**

The screenshot shows a web interface for an alert titled "Rockwell Code Download". The alert is categorized as "Configuration Events" and has a status of "Medium" and "Not resolved". The event details include:

- Event ID: 12413
- Time: 01:46:30 PM · Feb 4, 2021
- Source: PCS Eng. Station
- Destination: plc_tesim
- Address: 172.16.3.10
- Destination Address: 172.16.2.102

The alert description states: "Code was downloaded from an engineering station to the controller".

Two informational boxes are present:

- Why is this important?:** The system detected a change in the controller code that was made.
- Suggested Mitigation:** 1) Check whether the change was made as part of scheduled work and whether the source of the

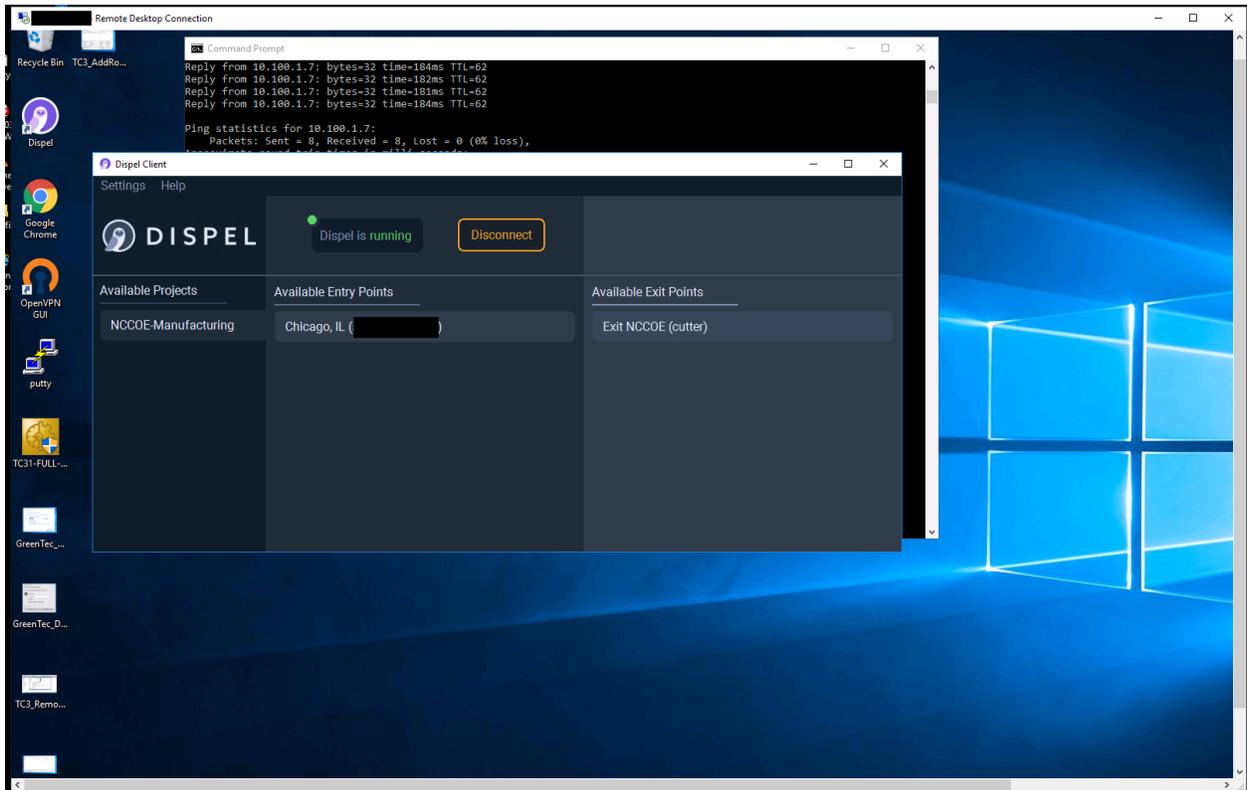
1544 **D.8.2 Build 2**1545 **D.8.2.1 Configuration**

- 1546 ▪ Behavior Anomaly Detection: eyeInspect
 - 1547 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1548 ▪ Remote Access, User Authentication/User Authorization: Dispel
 - 1549 • Dispel VDI is configured to allow authorized users to access PCS environment through the
 - 1550 Dispel Enclave to the Dispel Wicket.

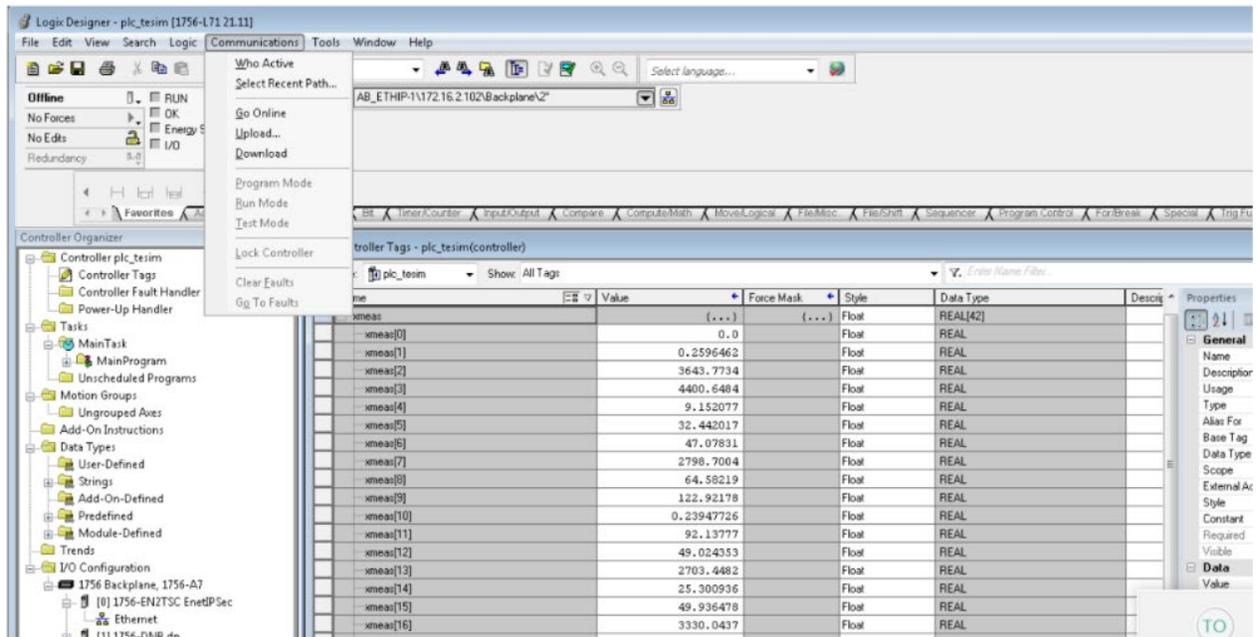
1551 **D.8.2.2 Test Results**

1552 As shown in [Figure D-81](#) the authorized user establishes a session into the manufacturing environment
 1553 using the Dispel VDI. The user connects to the engineering workstation and launches the Studio 5000
 1554 Logix Designer as shown in [Figure D-82](#) to modify the PLC logic. [Figure D-83](#), [Figure D-84](#) and [Figure D-85](#)
 1555 show that Forescout is able to detect the traffic between the engineering workstation and the PLC,
 1556 including details of the Stop command and Download command.

1557 Figure D-81: Remote Access to Systems in PCS Network is Being Established Through Dispel



1558 Figure D-82: Modifying the Parameters for the Allen-Bradley PLC Controller Using Studio 5000



DRAFT

1559 Figure D-83: Forescout Alerts Showing It Detected the Traffic Between the Engineering Workstation
1560 and the PLC

Timestamp	Event name(s)	Sensor	Engine	Profile	Status	Severity	Source address	Destination address	Dest. Port	L7 Proto	Case ID
Oct 13, 2020 13:47:52	(FEA Exit) Message t...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020 13:47:52	(FEA Exit) Message t...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020 13:47:52	(FEA Exit) Message t...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020 13:47:52	(FEA Exit) Message t...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020 13:46:49	ETHIP controller star...	senso...	Indu...	-	Not analyz...	High L	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020 13:46:49	Message type not w...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818 (TCP)	ETHIP	
Oct 13, 2020	Message type not w...	senso...	Co...	8-TCP c...	Not analy...	High M	172.16.3.10 (fg...	172.16.2.102 (...	44818	ETHIP	

1561 Figure D-84: Forescout Alert Details for the Stop Command Issued to the PLC

Summary

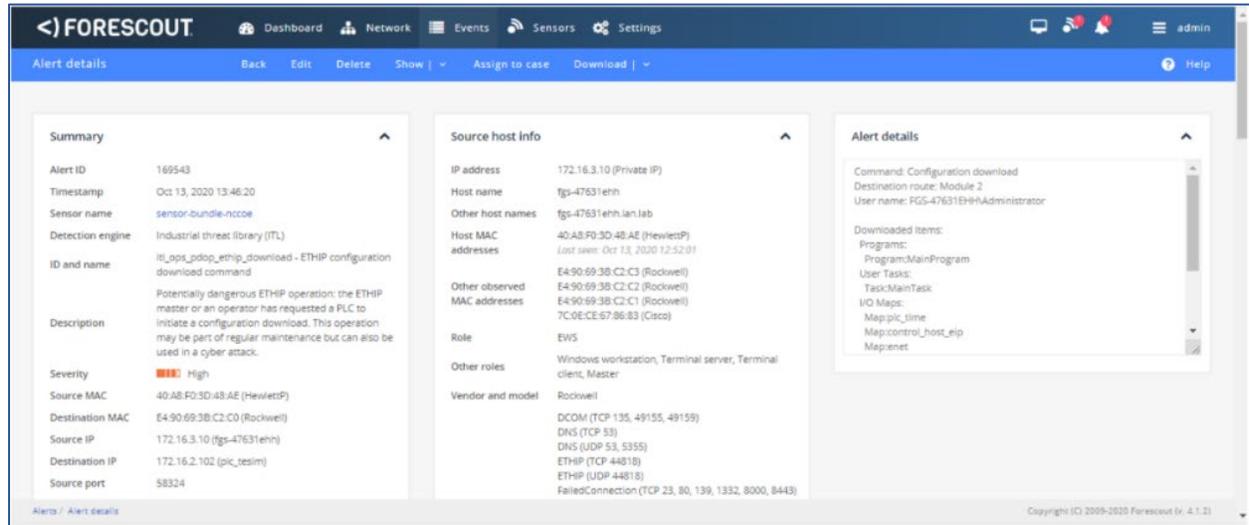
Alert ID: 169537
Timestamp: Oct 13, 2020 13:46:10
Sensor name: sensor-bundle-nccoe
Detection engine: Industrial threat library (ITL)
ID and name: It_ops_pdot_ethip_controller_stop - ETHIP controller stop command
Description: Potentially dangerous ETHIP operation: the ETHIP master or an operator has requested a PLC to stop. This operation may be part of regular maintenance but can also be used in a Denial of Service attack.
Severity: High
Source MAC: 40:A8:F0:3D:48:AE (HewlettP)
Destination MAC: E4:90:69:3B:C2:C0 (Rockwell)
Source IP: 172.16.3.10 (fgs-47631ehh)
Destination IP: 172.16.2.102 (pic_testim)
Source port: 58324
Destination port: 44818

Source host info

IP address: 172.16.3.10 (Private IP)
Host name: fgs-47631ehh
Other host names: fgs-47631ehh.lan.lab
Host MAC addresses: 40:A8:F0:3D:48:AE (HewlettP)
Last seen: Oct 13, 2020 12:52:01
Other observed MAC addresses: E4:90:69:3B:C2:C3 (Rockwell), E4:90:69:3B:C2:C2 (Rockwell), E4:90:69:3B:C2:C1 (Rockwell), 7C:0E:CE:67:86:83 (Cisco)
Role: EWS
Other roles: Windows workstation, Terminal server, Terminal client, Master
Vendor and model: Rockwell
DCOM (TCP 135, 49155, 49159)
DNS (TCP 53)
DNS (UDP 53, 5355)
ETHIP (TCP 44818)
ETHIP (UDP 44818)
FailedConnection (TCP 23, 80, 139, 1332, 8000, 8443)

Alert details

Command: Stop controller
Destination route: Module 2
User name: FGS-47631EHHAdministrator

1562 **Figure D-85: Forescout Alert Details for the Configuration Download Command**1563 **D.8.3 Build 3**1564 **D.8.3.1 Configuration**1565 **Behavior Anomaly Detection: Dragos**

- 1566 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
- 1567 Control LAN.

1568 **Remote Access: Cisco VPN**

- 1569 • Configured to allow authorized VPN users to access to ConsoleWorks web interface.

1570 **User Authentication/User Authorization: ConsoleWorks**

- 1571 • Configured for accessing the CRS environment.

1572 **D.8.3.2 Test Results**

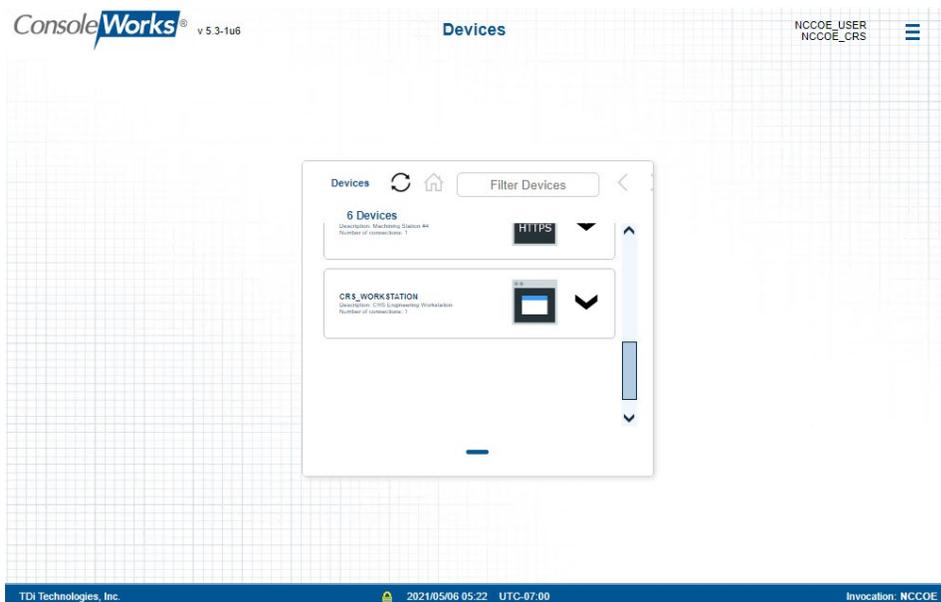
1573 In this build, a remote session to the CRS workstation is established to perform PLC file operations as
 1574 shown in [Figure D-86](#) and [Figure D-87](#). Dragos is able to detect the PLC file modifications as shown in
 1575 [Figure D-88](#) with details shown in [Figure D-89](#).

DRAFT

1576 Figure D-86: VPN Connection to the Manufacturing Environment



1577 Figure D-87: Remote Access is Being Established through ConsoleWorks



1578 Figure D-88: Dragos Notification Manager Showing Detection of the Transfer of PLC Logic File to the
1579 Beckhoff PLC

View	Severity	ID	Occurred At	Detection Quadrants	Summary	Message	Detected By	Asset IDs	Source IP(s)	Dest. IP(s)	Other IP(s)
	4	138828	02/12/21, 02:25:43...	Indicator	TR 2020-27 related indicator detected in the environment	8 logs matching on the TR 2020-27 Indicator 72.21.91.21 were seen in...	Dropbox SOC: TR 2020-27	144.192			72.21.91.21 ...
	3	138827	02/12/21, 02:23:14...	Change Detection	New Logic Applied To PLC via Beckhoff ADS	New Logic Applied To PLC via Beckhoff ADS	Beckhoff ADS Logic Change		35.15	192.168.0.28	192.168.0.30
	2	138842	02/12/21, 02:49:51...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138841	02/12/21, 02:49:52...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138840	02/12/21, 02:49:56...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138929	02/12/21, 02:49:54...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138838	02/12/21, 02:49:53...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138927	02/12/21, 02:49:50...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138836	02/12/21, 02:49:47...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138925	02/12/21, 02:49:38...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138834	02/12/21, 02:50:00...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138833	02/12/21, 02:50:01...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138932	02/12/21, 02:50:00...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				
	2	138831	02/12/21, 02:50:03...	Threat Behavior	Multiple Logons Detected	Multiple Logons Detected by admin, who quickly logged into at least 3 ...	Authentication to Multiple Hosts				

1580 **Figure D-89: Dragos Alert Details for the PLC Logic File Download**

DETECTION INFORMATION

WHAT HAPPENED:
New Logic Applied To PLC via Beckhoff ADS

OCCURRED AT:
02/12/21, 03:23 PM UTC

SOURCE:
Network Traffic

ZONES:
CRS - Level 1

ACTIVITY GROUP:
N/A

ICS CYBER KILLCHAIN STEP:
None

QUERY-FOCUSED DATASETS:
No Applicable Query-Focused Datasets

PLAYBOOKS:
No Associated Playbooks

CASES:
No Cases Linked

DETECTED BY:
Beckhoff ADS Logic Change

DETECTION QUAD:
Change Detection

ICS ATTACK TACTIC:
Execution

ICS ATTACK TECHNIQUE:
Change Program State

NOTIFICATION RECORD:
No Associated Record

NOTIFICATION COMPONENTS:
View in Kibana

ASSOCIATED ASSETS

View	Type	ID	Name	IP	OS
VIEW	Engineering W	35	POLARIS	192.168.0.20	svc
VIEW	Process Suppl	15	Supervisory PLC	192.168.0.20	dst

RELATED NOTIFICATIONS (0)

ID	Occurred At	Summary
No Related Notifications		

Navigation: < PREVIOUS | CLOSE | CREATE A RULE | CREATE CASE | NEXT >

1581 **D.8.4 Build 4**1582 **D.8.4.1 Configuration**

- 1583
- 1584 ■ Behavior Anomaly Detection: Azure Defender for IoT
 - 1584 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1585 Control LAN.
 - 1586 ■ Remote Access, User Authentication/User Authorization: Dispel
 - 1587 ● Dispel VDI is configured to allow authorized users to access the PCS environment through
 - 1588 the Dispel Enclave to the Dispel Wicket.

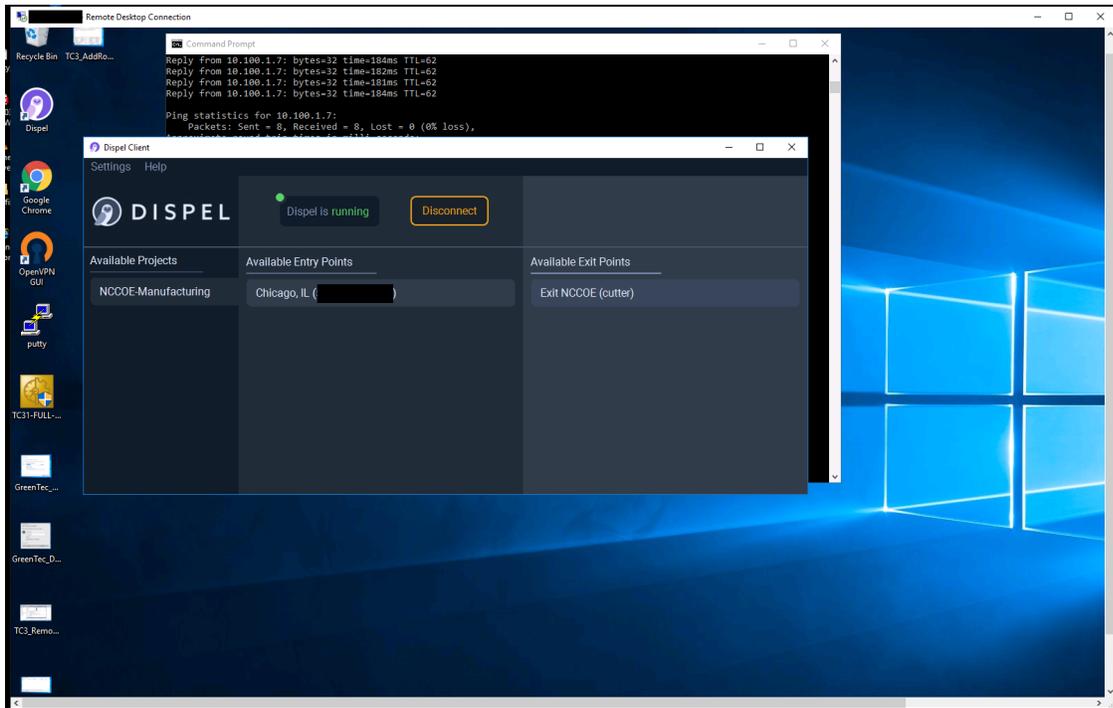
1589 **D.8.4.2 Test Results**

1590 [Figure D-90](#) and [Figure D-91](#) show the connection to the CRS environment through the Dispel VDI. The

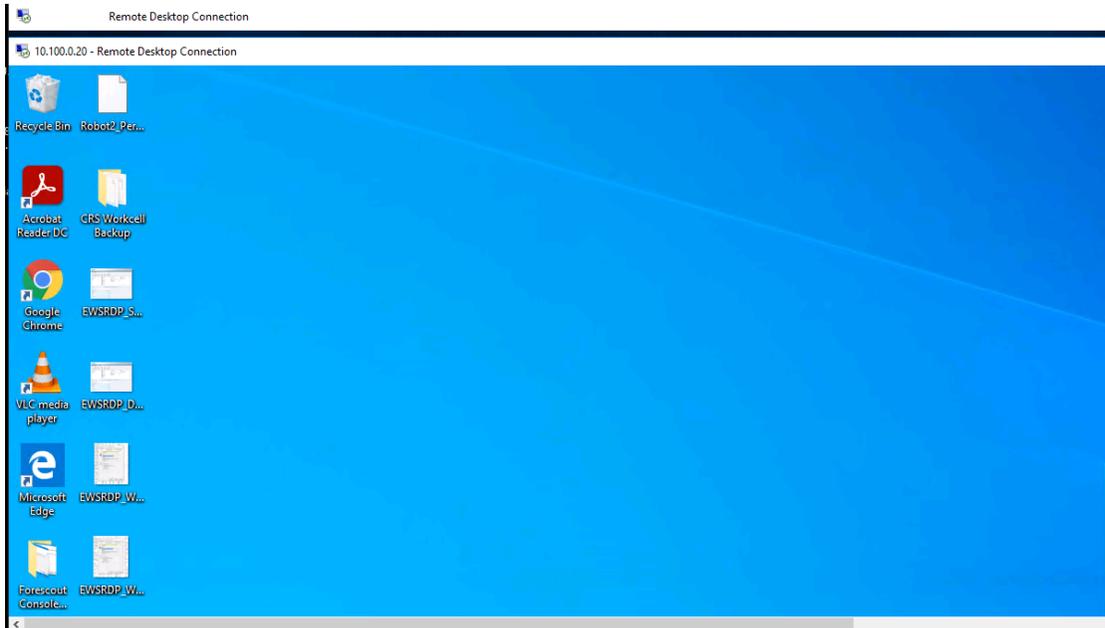
1591 changes to the PLC programs are detected by Azure Defender for IoT, as shown in [Figure D-92](#), because

1592 the Dispel VDI is not an authorized programming device.

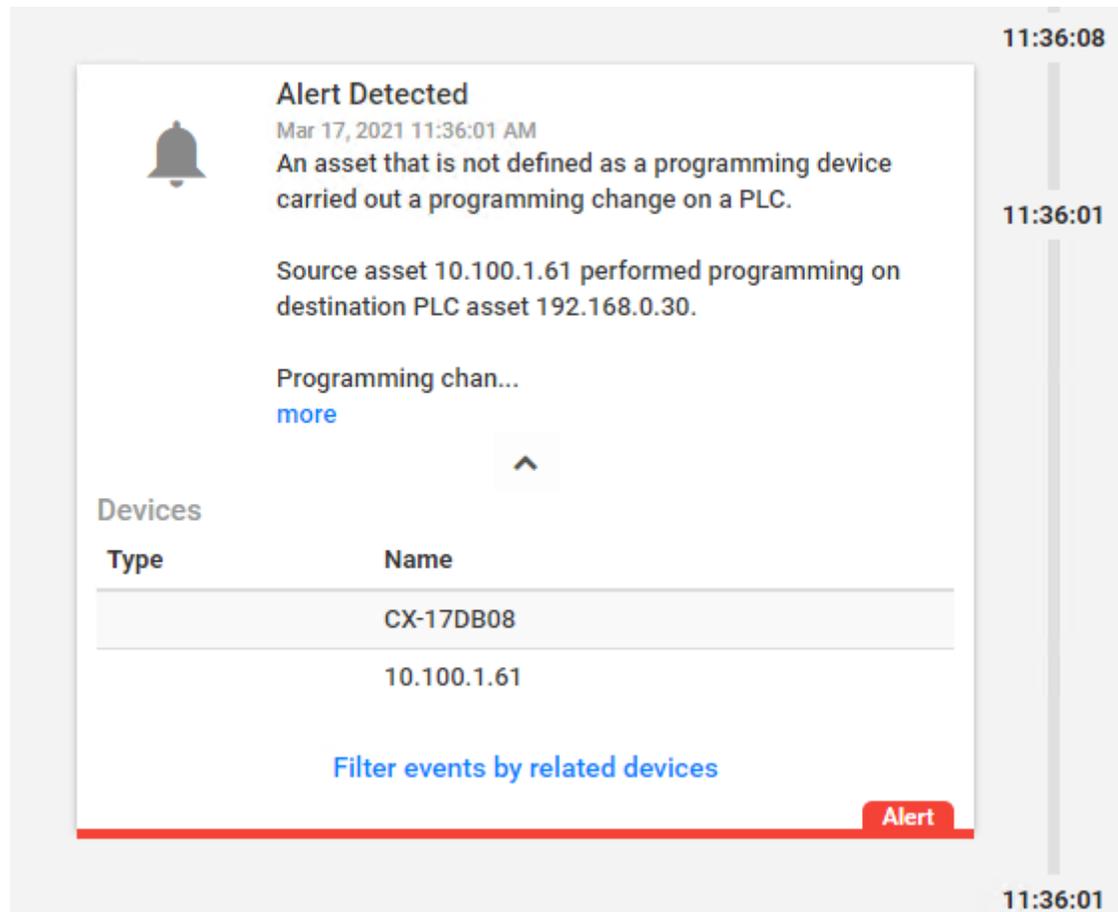
1593 Figure D-90: Dispel VDI with Interface for Connecting Through Dispel Enclave to Dispel Wicket



1594 Figure D-91: Nested RDP Connections Showing Dispel Connection into the CRS Workstation



1595 Figure D-92: Azure Defender for IoT Alert for the Unauthorized PLC Programming

1596 **D.9 Executing Scenario 9: Protect from Modification of Historian Data**

1597 An attacker who has already gained access to the corporate network attempts to modify historian
 1598 archive data located in the DMZ. The expected result is the behavioral anomaly detection products
 1599 detect the connection to the historian archive. File modification is prevented by the file integrity
 1600 checking capability.

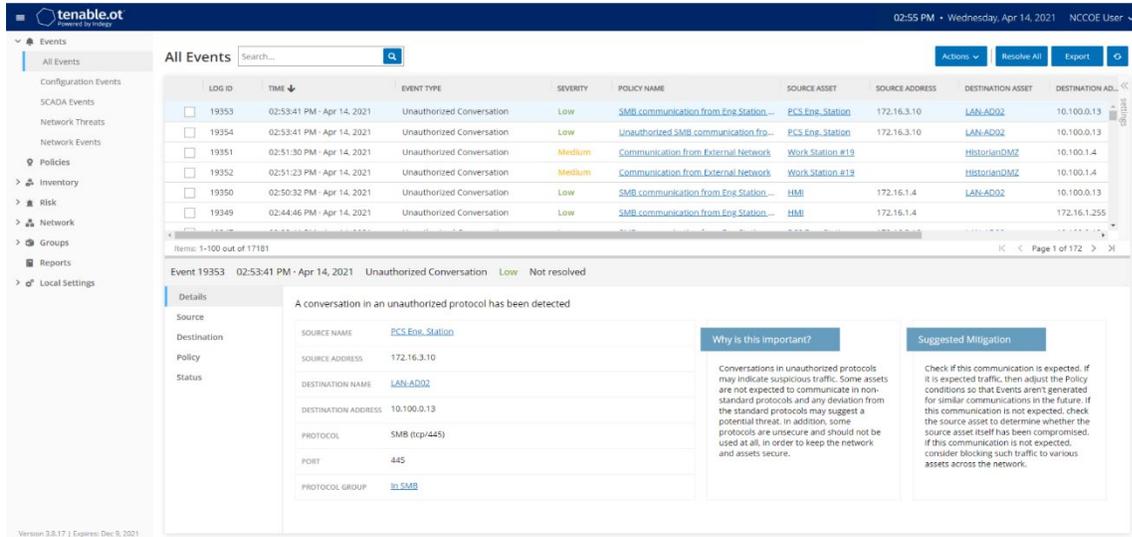
1601 **D.9.1 Build 1**1602 *D.9.1.1 Configuration*

- 1603 ▪ Behavior Anomaly Detection: Tenable.ot
 - 1604 • Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1605 ▪ File Integrity Checking: ForceField
 - 1606 • PI Server is configured to use ForceField drive.

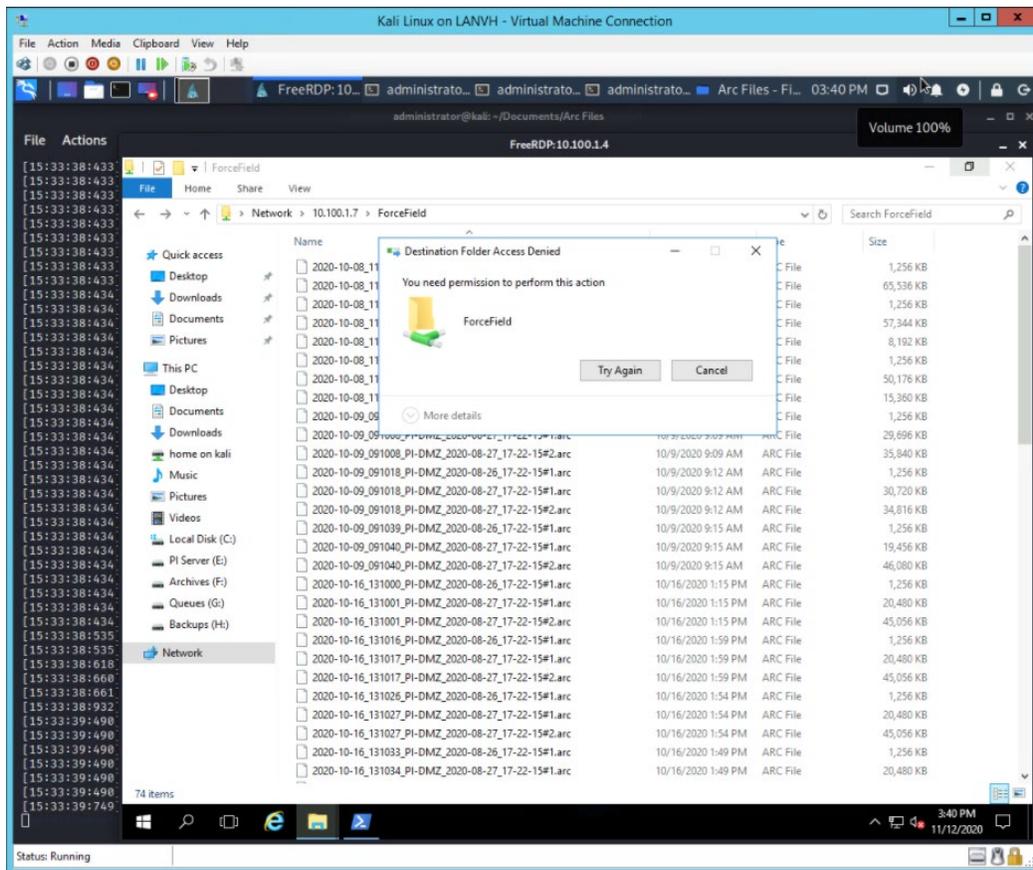
1607 *D.9.1.2 Test Results*

1608 Figure D-93 shows Tenable.ot detecting the remote access connections. [Figure D-94](#) shows that
1609 GreenTec successfully blocks the attacker from deleting archive data.

1610 **Figure D-93: Tenable.ot alert Showing SMB Connection from an External Workstation to the Historian**



1611 Figure D-94: GreenTec Denies Modification and Deletion File Operations in the Protected Drive



1612 D.9.2 Build 2

1613 D.9.2.1 Configuration

- 1614 ■ Behavior Anomaly Detection: eyeInspect
 - 1615 ● Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1616 ■ File Integrity Checking: ForceField
 - 1617 ● PI Server is configured to use ForceField drive.

1618 D.9.2.2 Test Results

1619 Forescout detects the remote session as shown in [Figure D-95](#). When the user attempts to alter a file on
 1620 the protected drive, GreenTec denies the operation as shown in [Figure D-96](#).

1621 Figure D-95: Forescout Alert Showing Network Connection from the Corporate Network to the
1622 Historian

The screenshot displays the Forescout web interface for an alert. The interface is divided into three main sections: Summary, Source host info, and Alert Details.

Summary:

- Alert ID: 330437
- Timestamp: Nov 12, 2020 15:33:31
- Sensor name: sensor-bundle-nccoe
- Detection engine: Communication patterns (LAN CP)
- Profile: 8 - TCP communications
- Severity: Medium (indicated by a yellow bar)
- Source MAC: (Cisco)
- Destination MAC: 00:15:5D:02:0D:03 (Microsoft)
- Source IP: 129.6.1.3 (Public IP)
- Destination IP: 10.100.1.4 (pl-dmz)
- Source port: 49972
- Destination port: 3389
- L2 proto: Ethernet
- L3 proto: IP
- L4 proto: TCP
- L7 proto: RDP
- TCP stream opened in hot start mode: false

Source host info:

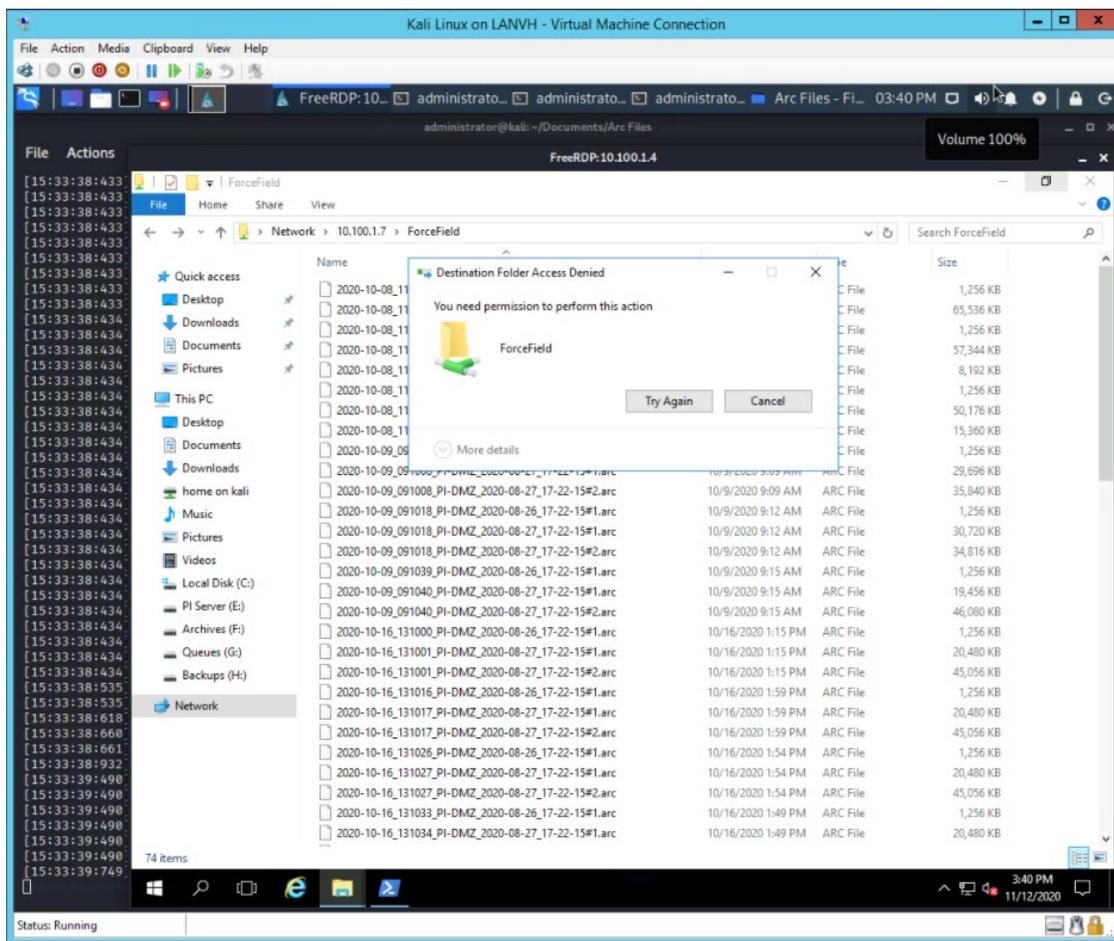
- IP address: 129.6.1.3 (Public IP)
- Host MAC addresses: Unknown
- Other observed MAC addresses: E4:90:69:3B:C2:C0 (Rockwell), 7C:0E:CE:67:86:88 (Cisco)
- Role: Terminal client
- Vendor and model: Rockwell
- Client protocols: RDP (TCP 3389)
- Server protocols: NotAKnownOne (TCP 4444)
- Purdue level: 4 - Site business network
- Security Risk: 3.2 (indicated by a green bar)
- Operational Risk: 0.0 (indicated by a blue bar)
- Criticality: L (indicated by a green bar)
- Known vulnerabilities: 0
- Related alerts: 8 (Show)
- First seen: Oct 14, 2020 11:56:54
- Last seen: Nov 12, 2020 15:45:56

Alert Details:

- ID and name: lan_cp_cnw_c - Communication pattern not whitelisted
- Description: Communication pattern not whitelisted; the source and destination hosts are whitelisted in some communication rules, but not with this combination
- Triggering rule/default action: alert

At the bottom left of the interface, it says "Alerts / Alert details". At the bottom right, it says "Copyright (C) 2009-2020 Forescout (v. 4.1.2)".

1623 Figure D-96: GreenTec Denies Modification and Deletion File Operations in the Protected Drive



1624 D.9.3 Build 3

1625 D.9.3.1 Configuration

- 1626
- 1627 ■ Behavior Anomaly Detection: Dragos
 - 1628 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and Control LAN.
 - 1629 ■ File Integrity Checking: ForceField
 - 1630 ● PI Server is configured to use ForceField drive.

1631 D.9.3.2 Test Results

1632 Dragos detects the remote session as shown in [Figure D-97](#). When the user attempts to alter a file on
 1633 the protected drive, GreenTec denies the operation as shown in [Figure D-98](#).

1634 Figure D-97: Dragos Detection of RDP Session from an External Network to the Historian

The screenshot displays a security dashboard for an "RDP Negotiation Request". The interface is divided into several key sections:

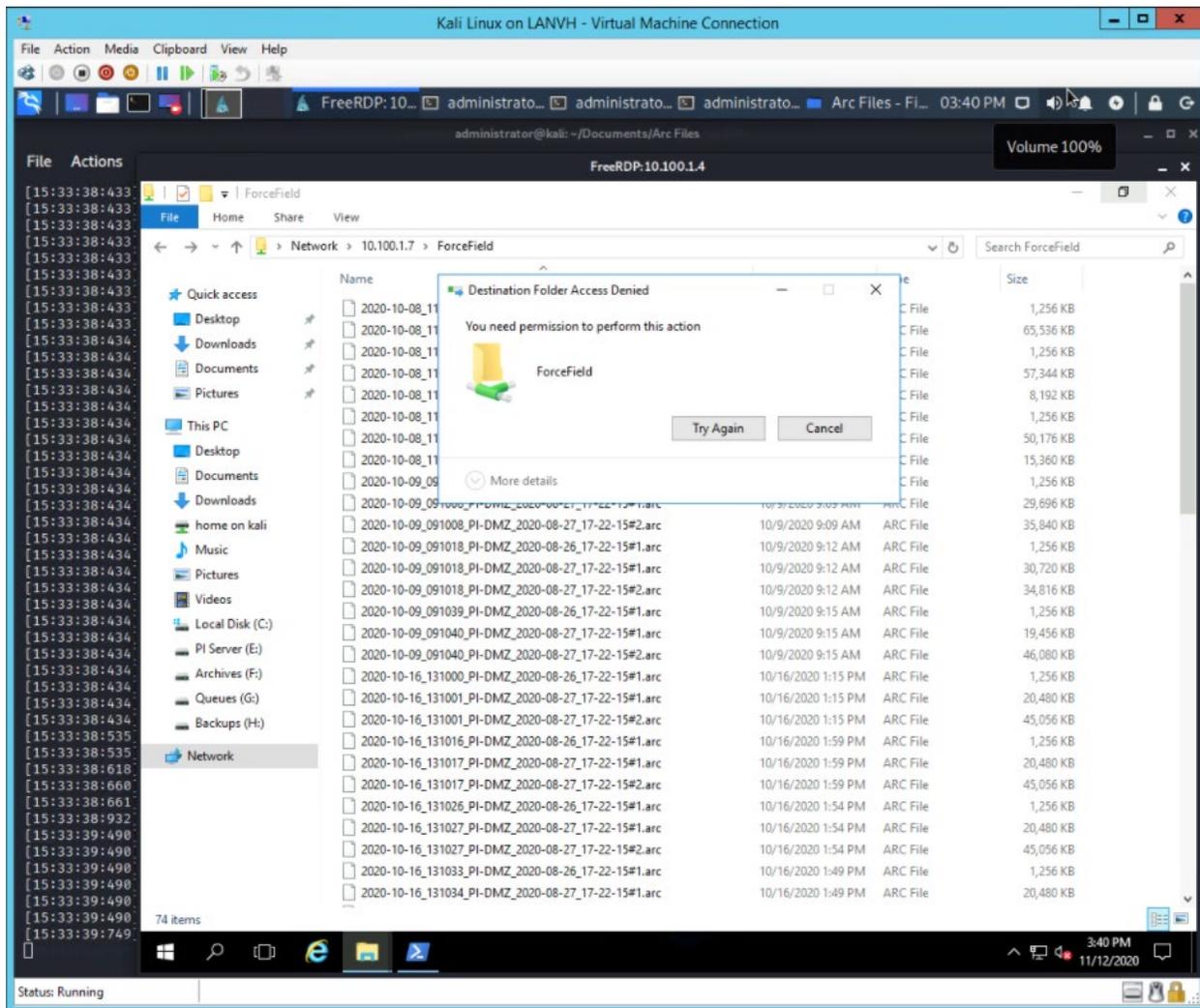
- DETECTION INFORMATION:** This section provides details about the event, including:
 - WHAT HAPPENED:** RDP Negotiation Request
 - OCCURRED AT:** 10/17/2023, 10:15:10 UTC
 - COUNT:** 1
 - DETECTED BY:** RDP Port 1 Mismatch
 - DETECTION QUAD:** Threat Behavior
 - ACTIVITY GROUP:** RENDOME
 - MITRE ATTACK FOR ICS TACTIC:** Command And Control (C2)
 - QUERY-FOCUSED DATASETS:** No Applicable Query Focused Datasets
 - PLAYBOOKS:** No Associated Playbooks
 - CASES:** No Cases Linked
 - LAST SEEN:** 10/17/2023, 10:15:10 UTC
 - STATE:** UNRESOLVED
 - SOURCE:** Network Traffic
 - ZONES:** DMZ, NIST
 - ICS CYBER KILLCHAIN STEP:** Stage 1: APT on Disposables
 - MITRE ATTACK FOR ICS TECHNIQUE:** T8080: Commonly Used Port
 - NOTIFICATION RECORD:** No Associated Record
 - NOTIFICATION COMPONENTS:** View in Kitana
- ASSOCIATED ASSETS:** A table listing assets involved in the event:

View	Type	ID	Name	Dir
VIEW	Windows Serv	85	Asset 85	10.100.1.4
VIEW	Asset	864	Asset 864	800
- COMMUNICATIONS SUMMARY:** A diagram showing a connection between "Windows Server Microsoft Corporation Element 10.100.1.4" and "Asset". Below the diagram is a table of communication details:

Protocol	Client	Ephemeral Ports	Server	Server Ports	Tx Bytes	Rx Bytes
SSL			10.100.1.4		2.1 MB	15.9 MB
- RELATED NOTIFICATIONS:** A table with columns for ID and Occurred At. The current view shows "No Related Notifications".

At the bottom of the dashboard, there are navigation controls including "Showing 1 to", "ROWS PER PAGE" (set to 10), and buttons for "PREV", "CLOSE", "CREATE A RULE", "CREATE CASE", and "NEXT".

1635 Figure D-98: GreenTec Denies Modification and Deletion File Operations in the Protected Drive



1636 D.9.4 Build 4

1637 D.9.4.1 Configuration

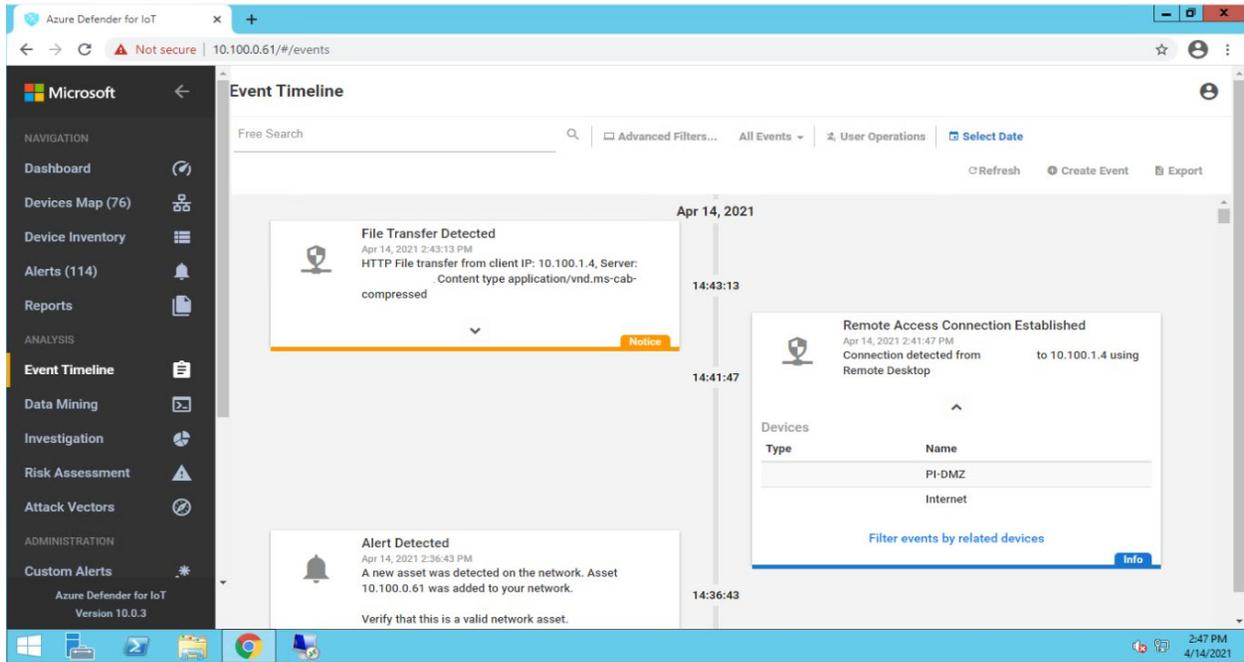
- 1638
- 1639 ■ Behavior Anomaly Detection: Azure Defender for IoT
 - 1640 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and Control LAN.
 - 1641 ■ File Integrity Checking: ForceField
 - 1642 ● PI Server is configured to use ForceField drive.

DRAFT

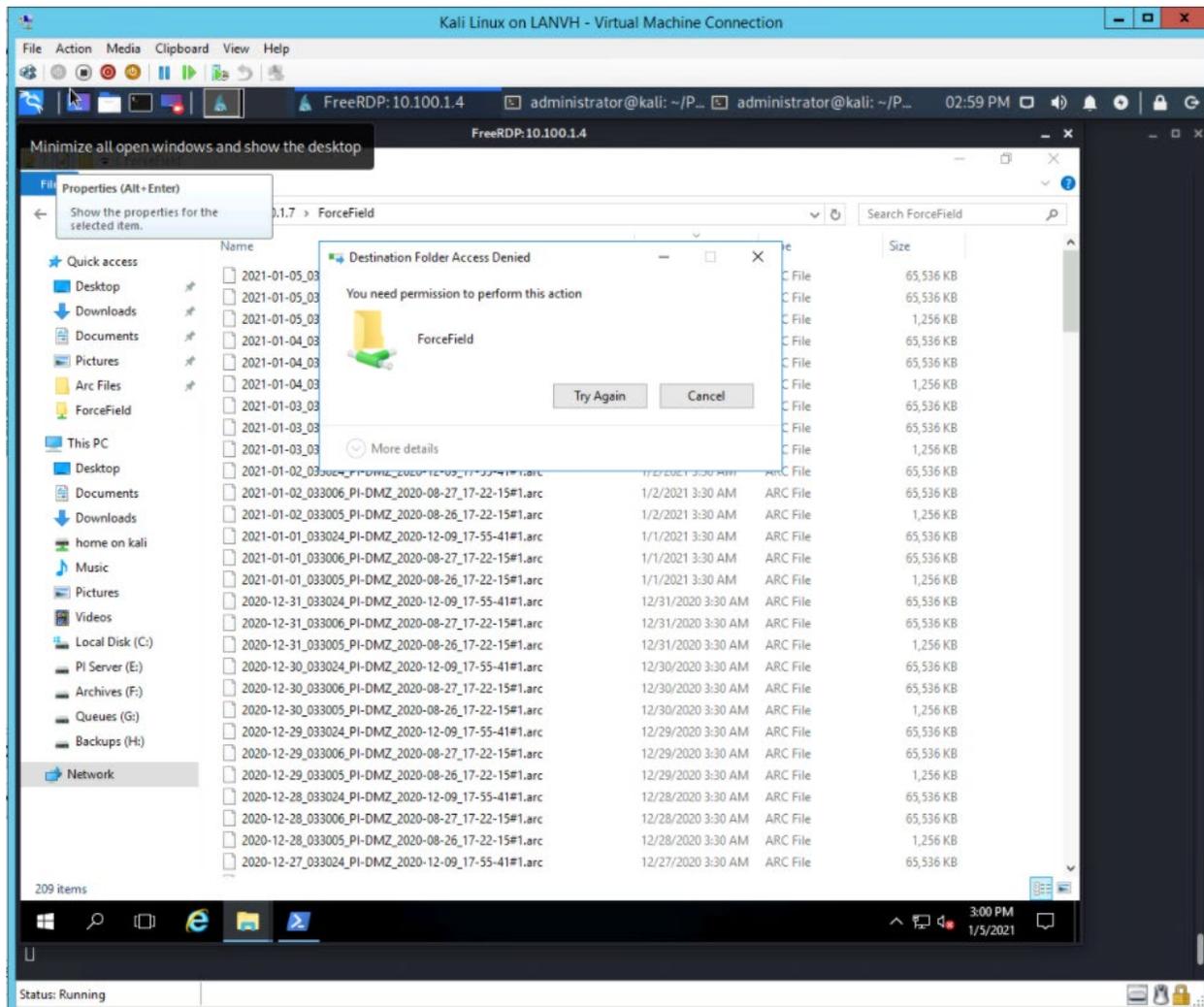
1643 *D.9.4.2 Test Results*

1644 The connection to the Historian data storage was detected by Azure Defender for IoT as shown in Figure
1645 D-99. [Figure D-100](#) shows a Windows error message after attempting to overwrite protected Historian
1646 files.

1647 **Figure D-99: Azure Defender for IoT Event Timeline Showing the Remote Access Connection to the**
1648 **Historian**



1649 Figure D-100: GreenTec Denies Modification and Deletion File Operations in the Protected Drive

1650 **D.10 Executing Scenario 10: Detect Sensor Data Manipulation**

1651 A sensor in the manufacturing system sends out-of-range data values to the Historian. The expected
 1652 result is the behavioral anomaly detection (data historian) capability alerts on out-of-range data.

1653 **D.10.1 All Builds**1654 **D.10.1.1 Configuration**

- 1655
- 1656 ■ Behavior Anomaly Detection: PI Server
 - 1657 • Configured to receive process data from across the manufacturing system.
 - Configured to perform analysis on incoming data points.

1658 **D.10.1.2 Test Results**

1659 The Historian process monitoring capabilities provided by the PI System are able to monitor out-of-
 1660 range sensor readings and generate alerts. Figure D-101 shows the PI Server's event frame alerts on the
 1661 out-of-range reactor pressure readings in the PCS.

1662 **Figure D-101: PI Server's Event Frames Showing Out-of-Range Sensor Readings for the Reactor**
 1663 **Pressure**

#	Name	Duration	Start Time	End Time	Description	Ca...
1	Reactor High Pressure 2021-01-29 15:49:37.238	0:00:40.999	1/29/2021 3:49:...	1/29/2021 3:50:...		
2	Reactor High Pressure 2021-01-29 15:52:49.229	0:00:38.097	1/29/2021 3:52:...			

1664 **D.11 Executing Scenario 11: Detect Unauthorized Firmware Modification**

1665 An authorized user accesses the system remotely and performs an unauthorized change of the firmware
 1666 on a PLC. The expected result is the behavioral anomaly detection tools will alert on the new firmware.

1667 The behavior anomaly detection tools can detect changes to the firmware. Firmware change detection
 1668 needs to be correlated with the maintenance management system to determine if the firmware change
 1669 was authorized and approved. This was not demonstrated as part of this scenario.

1670 **D.11.1 Build 1**1671 **D.11.1.1 Configuration**

- 1672 ■ Behavior Anomaly Detection: Tenable.ot
 - 1673 ● Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1674 ■ Remote Access: Cisco VPN
 - 1675 ● Configured to allow authorized VPN users access to ConsoleWorks web interface.

DRAFT

- 1676 ■ User Authentication/User Authorization: ConsoleWorks
- 1677 ● Configured for accessing the PCS environment.

1678 *D.11.1.2 Test Results*

1679 Figure D-102 depicts the list of the events detected by Tenable.ot resulting from the firmware change.
1680 The details of one of the alerts are shown in Figure D-103

1681 **Figure D-102: Tenable.ot Detects a Collection of Events Generated by a Firmware Change**

LOG ID	TIME	EVENT TYPE	SEVERITY	POLICY NAME	SOURCE ASSET	SOURCE ADDRESS	DESTINATION ASSET	DESTINATION AD...	PROTOCOL
12436	02:28:03 PM - Feb 4, 2021	Change in Firmware...	High	Change in controller firmware...	Comm_Adapter #1				Unknown
12434	02:26:41 PM - Feb 4, 2021	Rockwell Module ...	Low	Rockwell Module Restart	PCS_Eng_Station	172.16.3.10	Comm_Adapter #1	172.16.2.102	OP (Rsp)
12433	02:25:48 PM - Feb 4, 2021	Rockwell Firmware...	High	Rockwell Firmware Download	PCS_Eng_Station	172.16.3.10	Comm_Adapter #1	172.16.2.102	OP (Rsp)
12427	02:11:34 PM - Feb 4, 2021	Rockwell Module ...	Low	Rockwell Module Restart	PCS_Eng_Station	172.16.3.10	Term_Module	172.16.2.102	OP (Rsp)
12426	02:09:50 PM - Feb 4, 2021	Rockwell Module ...	Low	Rockwell Module Restart	PCS_Eng_Station	172.16.3.10	Term_Module	172.16.2.102	OP (Rsp)
12423	02:05:55 PM - Feb 4, 2021	Rockwell Tag Dete...	Low	Rockwell Delete Tag	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12422	02:05:55 PM - Feb 4, 2021	Rockwell Tag Crl...	Low	Rockwell Create Tag	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12421	02:02:47 PM - Feb 4, 2021	Change in State	Medium	Change in controller state	chk_station				Unknown
12416	01:47:47 PM - Feb 4, 2021	Change in Key Sw...	High	Change in controller key state	chk_station				OP (Rsp)
12414	01:46:52 PM - Feb 4, 2021	Rockwell PLC Start	Low	Rockwell PLC Start	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12413	01:46:30 PM - Feb 4, 2021	Rockwell Code Dtl...	Medium	Rockwell Code Download	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12412	01:46:27 PM - Feb 4, 2021	Rockwell PLC Stop	High	Rockwell PLC Stop	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12410	01:45:06 PM - Feb 4, 2021	Rockwell Go Online	Low	Rockwell Online Session	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12408	01:42:21 PM - Feb 4, 2021	Rockwell Go Online	Low	Rockwell Online Session	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
12406	01:41:28 PM - Feb 4, 2021	Rockwell Go Online	Low	Rockwell Online Session	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
9133	04:33:00 PM - Jan 25, 2021	Rockwell Go Online	Low	Rockwell Online Session	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)
9121	04:02:47 PM - Jan 25, 2021	Change in Key Sw...	High	Change in controller key state	chk_station				OP (Rsp)
9120	04:00:47 PM - Jan 25, 2021	Change in State	Medium	Change in controller state	chk_station				Unknown
9119	03:47:47 PM - Jan 25, 2021	Change in Key Sw...	High	Change in controller key state	chk_station				OP (Rsp)
9114	03:47:47 PM - Jan 25, 2021	Change in State	Medium	Change in controller state	chk_station				Unknown
9110	03:38:51 PM - Jan 25, 2021	Rockwell Code Up...	Low	Rockwell Code Upload	PCS_Eng_Station	172.16.3.10	chk_station	172.16.2.102	OP (Rsp)

1682 **Figure D-103: Details for One of the Alerts Showing the Firmware Change**

Event 12436 02:28:03 PM - Feb 4, 2021 Change in Firmware Version High Not resolved

Details
A change in the firmware version was detected

Affected Assets
SOURCE NAME: Comm_Adapter #1

Status
SOURCE ADDRESS: 172.16.2.102 | 172.16.4.102
BACKPLANE NAME: Backplane #1
OLD FIRMWARE VERSION: 10.007
NEW FIRMWARE VERSION: 10.010

Why is this important?
A change in the firmware version was detected. Such a change can occur over the network or through physical access to the device. An attacker may use firmware changes to alter the functionality of the asset, insert backdoors or disrupt normal operations.

Suggested Mitigation
1) Check if the change was made as part of scheduled work.
2) If this was not part of a planned operation, check if the network behavior of the asset has changed.

1683 *D.11.2 Build 2*

1684 *D.11.2.1 Configuration*

- 1685 ■ Behavior Anomaly Detection: eyeInspect
- 1686 ● Configured to receive packet streams from DMZ, Testbed LAN, and PCS VLAN 1 and 2.
- 1687 ■ Remote Access, User Authentication/User Authorization: Dispel

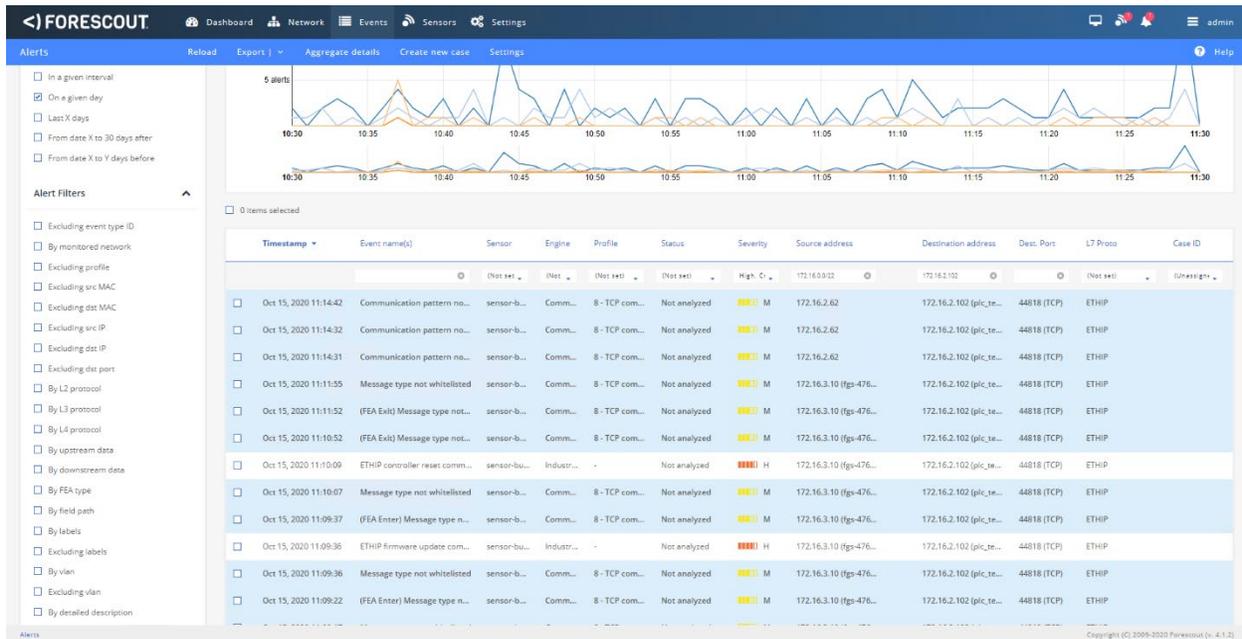
DRAFT

- 1688 • Dispel VDI is configured to allow authorized users to access the PCS environment through
1689 the Dispel Enclave to the Dispel Wicket.

1690 *D.11.2.2 Test Results*

1691 Figure D-104 shows the activities detected by Forescout as a result of firmware change. Figure D-104,
1692 [Figure D-105](#) and [Figure D-106](#) show more details on the alerts associated with the firmware update.

1693 **Figure D-104: Forescout Detects a Collection of Alerts Associated with the Firmware Change**



1694 Figure D-105: Alert Details Detected by Forescout for the Firmware Change

The screenshot displays the Forescout web interface for an alert titled "Alert details". The interface is organized into three main sections:

- Summary:**
 - Alert ID:** 186671
 - Timestamp:** Oct 15, 2020 11:09:36
 - Sensor name:** sensor-bundle-ncsoe
 - Detection engine:** Industrial threat library (ITL)
 - ID and name:** H_ops_pilot_ethip_firmware_update - ETHIP firmware update command
 - Description:** Potentially dangerous ETHIP operation: the ETHIP master or an operator has requested a PLC to initiate a firmware update. This operation may be part of regular maintenance but can also be used in a cyber attack.
 - Severity:** High
 - Source MAC:** 40:A8:F0:3D:48:AE (HewlettP)
 - Destination MAC:** E4:90:69:3B:C2:C0 (Rockwell)
 - Source IP:** 172.16.3.10 (fgs-47631.ehh)
 - Destination IP:** 172.16.2.102 (pic_tesim)
 - Source port:** 50753
 - Destination port:** 44818
 - L2 proto:** Ethernet
 - L3 proto:** IP
 - L4 proto:** TCP
 - L7 proto:** ETHIP
 - Status:** Not analyzed
 - Labels:**
 - User notes:**
- Source host info:**
 - IP address:** 172.16.3.10 (Private IP)
 - Host name:** fgs-47631.ehh
 - Other host names:** fgs-47631.ehh.lan.lab
 - Host MAC addresses:** 40:A8:F0:3D:48:AE (HewlettP)
Last seen: Oct 19, 2020 10:35:40
 - Other observed MAC addresses:** E4:90:69:3B:C2:C3 (Rockwell)
E4:90:69:3B:C2:C2 (Rockwell)
E4:90:69:3B:C2:C1 (Rockwell)
7C:0E:CE:67:86:88 (Cisco)
7C:0E:CE:67:86:83 (Cisco)
 - Role:** EWS
 - Other roles:** Windows workstation, Terminal server, Terminal client, Master
 - Vendor and model:** Rockwell
 - Client protocols:** DCOM (TCP 135, 49155, 49159)
DNS (TCP 53)
DNS (UDP 53, 5355)
ETHIP (TCP 44818)
ETHIP (UDP 44818)
FailedConnection (TCP 23, 80, 139, 1332, 8000, 8443)
HTTP (TCP 8080, 8530)
Kerberos (TCP 88)
LDAP (TCP 389)
LDAP (UDP 389)
NTP (UDP 123)
NetBIOS (UDP 137)
NotKnownOne (TCP 2500, 2501, 4444, 10005)
NotKnownOne (UDP 1514)
RDP (TCP 3389)
SMB (TCP 445)
SMB (UDP 138)
SSDP (UDP 1900)
SSH (TCP 22)
SSL (TCP 443, 3389, 10003, 10005)
Syslog (UDP 514)
DCOM (TCP 135, 6160)
FailedConnection (TCP 139, 445, 11731)
Nmap (TCP 6145)
- Alert details:**
 - Command:** Firmware update
 - Destination route:** Module 4
 - User name:** FGS-47631.EHH\Administrator
 - Updated firmware revision:** 3.4

At the bottom of the interface, there is a "Monitored networks" section with a table for Name, Address, and VLAN IDs. The footer includes "Alerts / Alert details" and "Copyright (c) 2009-2020 Forescout (v. 4.1.2)".

1695 **Figure D-106: ICS Patrol Scan Results Showing a Change Configuration was Made**

The screenshot displays the 'Scan details' window for a scan with ID 15. The scan was performed on Oct 15, 2020 at 11:14:28, with a duration of 01m37s. It was completed successfully. The scan targets were 172.16.2.102, using the PCS_Sensor scanning sensor. The scan policy was Admin User. The scan results table shows one target IP, 172.16.2.102, scanned with the PCS_Sensor, resulting in a 'Completed' status and an 'Updated' host status.

Target IP	Scanning sensor	Scan status	Host status
<input type="checkbox"/> 172.16.2.102	PCS_Sensor	Completed	Updated

1 to 1 items of 1

Result
Result is not available.

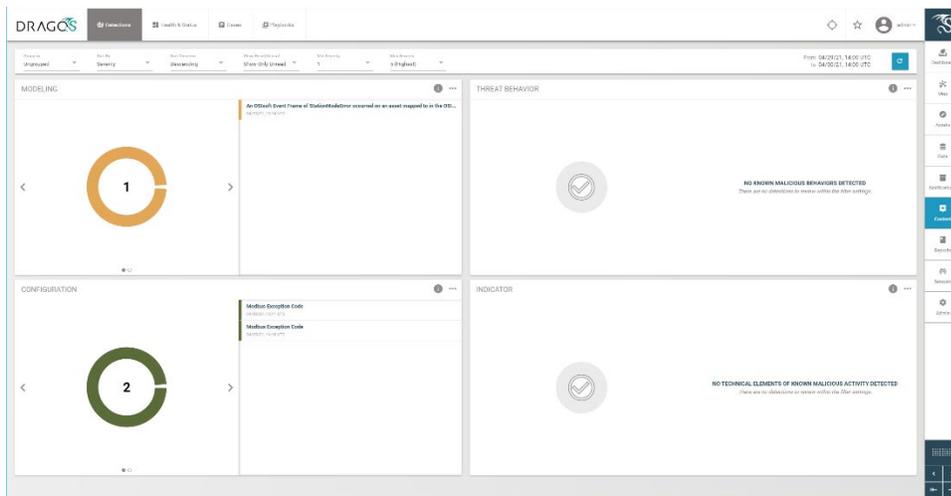
1696 **D.11.3 Build 3**1697 **D.11.3.1 Configuration**

- 1698
- 1698 ■ Remote Access: Cisco VPN
 - 1699 ● Configured to allow authorized VPN users to access only the ConsoleWorks web interface.
 - 1700 ■ User Authentication/User Authorization: ConsoleWorks
 - 1701 ● Configured to allow remote access to hosts in manufacturing environment.
 - 1702 ■ Behavior Anomaly Detection: Dragos
 - 1703 ● Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1704 Control LAN.

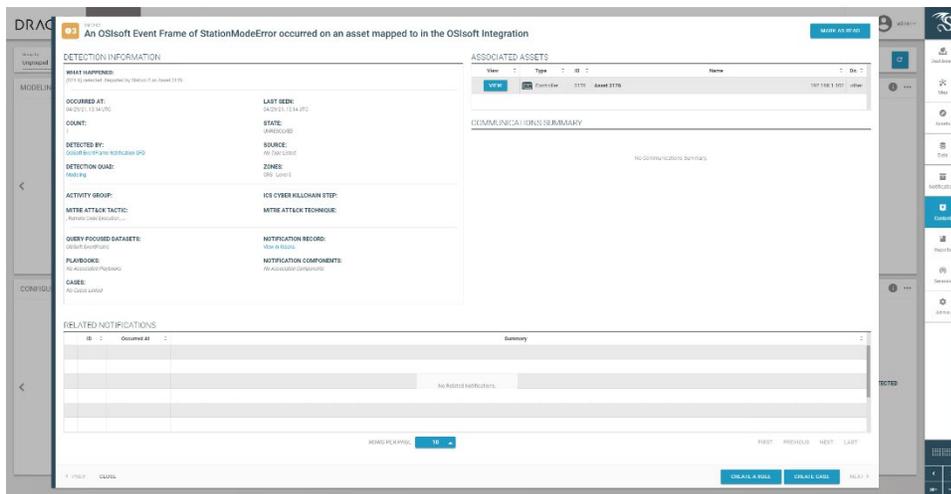
1705 **D.11.3.2 Test Results**

1706 Dragos detects the change to the firmware as shown on the dashboard in [Figure D-107](#) with details
1707 shown in [Figure D-108](#).

1708 Figure D-107: Dragos Dashboard Showing an Alert for Firmware Change



1709 Figure D-108: Details for Firmware Change Alert



1710 D.11.4 Build 4

1711 D.11.4.1 Configuration

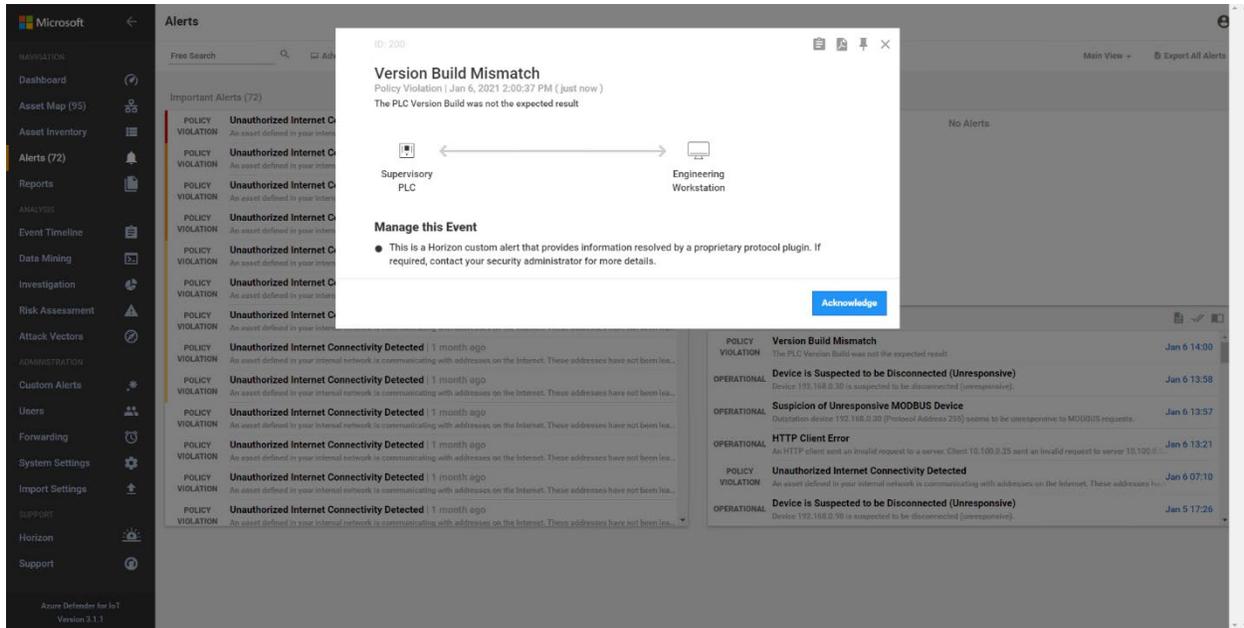
- 1712
 - Behavior Anomaly Detection: Azure Defender for IoT
 - 1713 • Configured to receive packet streams from DMZ, Testbed LAN, Supervisory LAN, and
 - 1714 Control LAN
 - 1715 ▪ Remote Access, User Authentication/User Authorization: Dispel
 - 1716 • Dispel VDI is configured as the engineering workstation to connect through the Dispel
 - 1717 Enclave to the Dispel Wicket to manage the Beckhoff PLC.

DRAFT

1718 *D.11.4.2 Test Results*

1719 Azure Defender for IoT alerts on the firmware update as shown below in Figure D-109.

1720 **Figure D-109: Azure Defender for IoT Alert Showing a Version Mismatch in the Firmware Build**



Appendix E Benefits of IoT Cybersecurity Capabilities

The National Institute of Standards and Technology's (NIST's) [Cybersecurity for the Internet of Things \(IoT\)](#) program supports development and application of standards, guidelines, and related tools to improve the cybersecurity of connected devices and the environments in which they are deployed. By collaborating with stakeholders across government, industry, international bodies, and academia, the program aims to cultivate trust and foster an environment that enables innovation on a global scale.

Cyber-physical components, including sensors and actuators, are being designed, developed, deployed, and integrated into networks at an ever-increasing pace. Many of these components are connected to the internet. IoT devices combine network connectivity with the ability to sense or affect the physical world. Stakeholders face additional challenges with applying cybersecurity controls as cyber-physical devices are further integrated.

NIST's Cybersecurity for IoT program has defined a set of device cybersecurity capabilities that device manufacturers should consider integrating into their IoT devices and that consumers should consider enabling/configuring in those devices. **Device cybersecurity capabilities** are cybersecurity features or functions that IoT devices or other system components (e.g., a gateway, proxy, IoT platform) provide through technical means (e.g., device hardware and software). Many IoT devices have limited processing and data storage capabilities and may not be able to provide these **device cybersecurity capabilities** on their own; they may rely on other system components to provide these technical capabilities on their behalf. **Nontechnical supporting capabilities** are actions that a manufacturer or third-party organization performs in support of the cybersecurity of an IoT device. Examples of nontechnical support include providing information about software updates, instructions for configuration settings, and supply chain information.

Used together, **device cybersecurity capabilities** and **nontechnical supporting capabilities** can help mitigate cybersecurity risks related to the use of IoT devices while assisting customers in achieving their goals. If IoT devices are integrated into industrial control system (ICS) environments, device cybersecurity capabilities and nontechnical supporting capabilities can assist in securing the ICS environment.

E.1 Device Capabilities Mapping

[Table E-1](#) lists the **device cybersecurity capabilities** and **nontechnical supporting capabilities** as they map to the NIST *Cybersecurity Framework* Subcategories of particular importance to this project. It is acknowledged that IoT devices vary in their capabilities, and there may not be a clear delineation between the **device cybersecurity capabilities** that are provided by the IoT devices and those provided by another system component. It is also understood that the capabilities of cyber-physical components are evolving, so many of the mappings are not necessarily exact.

In this project, the focus was on the engineering workstations and not on the manufacturing components. The mapping presented in [Table E-1](#) is a summary of both technical and nontechnical capabilities that would enhance the security of a manufacturing environment. It is acknowledged that many of the **device cybersecurity capabilities** may not be available in modern sensors and actuators and that other system elements (e.g., proxies, gateways) or other risk mitigation strategies (e.g., network segmentation) may be necessary.

Table E-1: Mapping of Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities to NIST *Cybersecurity Framework* Subcategories of the ICS Project

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
PR.AC-1: Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes.	<ul style="list-style-type: none"> ▪ Ability to uniquely identify the IoT device logically. ▪ Ability to uniquely identify a remote IoT device. ▪ Ability for the device to support a unique device ID. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to verify the identity of an IoT device. ▪ Ability to add a unique physical identifier at an external or internal location on the device authorized entities can access. ▪ Ability to set and change authentication configurations, policies, and limitations settings for the IoT device. ▪ Ability to create unique IoT device user accounts. ▪ Ability to identify unique IoT device user accounts. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to establish organizationally defined user actions for accessing the IoT device and/or device interface. ▪ Ability to enable automation and reporting of account management activities. ▪ Ability to establish conditions for shared/group accounts on the IoT device. ▪ Ability to administer conditions for shared/group accounts on the IoT device. ▪ Ability to restrict the use of shared/group accounts on the IoT device according to organizationally defined conditions. 	<ul style="list-style-type: none"> ▪ Providing details for how to establish unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing the details necessary to establish and implement unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing the details necessary to require unique identifiers for each IoT device associated with the system and critical system components within which it is used. ▪ Providing education explaining how to establish and enforce approved authorizations for logical access to IoT device information and system resources. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level. 	AC-2 IA-2 IA-4 IA-5 IA-8 IA-12
PR.AC-3: Remote access is managed.	<ul style="list-style-type: none"> ▪ Ability to configure IoT device access control policies using IoT device identity. <ul style="list-style-type: none"> ○ Ability for the IoT device to differentiate between authorized and unauthorized remote users. 	N/A	AC-17 AC-19 AC-20

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
	<ul style="list-style-type: none"> ▪ Ability to authenticate external users and systems. ▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface, including: <ul style="list-style-type: none"> ○ usage restrictions ○ configuration requirements ○ connection requirements ○ manufacturer established requirement ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability to control the IoT device’s logical interface (e.g., locally or remotely). ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. 		
<p>PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties.</p>	<ul style="list-style-type: none"> ▪ Ability to assign roles to IoT device user accounts. ▪ Ability to support a hierarchy of logical access privileges for the IoT device based on roles (e.g., admin, emergency, user, local, temporary). <ul style="list-style-type: none"> ○ Ability to establish user accounts to support role-based logical access privileges. ○ Ability to administer user accounts to support role-based logical access privileges. ○ Ability to use organizationally defined roles to define each user account’s access and permitted device actions. ○ Ability to support multiple levels of user/process account functionality and roles for the IoT device. 	<ul style="list-style-type: none"> ▪ Providing the tools, assistance, instructions, and other types of information to support establishing a hierarchy of role-based privileges within the IoT device. ▪ Providing details about the specific types of manufacturer’s needs to access the IoT device interfaces, such as for specific support, updates, ongoing maintenance, and other purposes. ▪ Providing documentation with instructions for the IoT device customer to follow for how to restrict interface connections that enable specific activities. ▪ Providing descriptions of the types of access to the IoT device that the manufacturer will require on an ongoing or regular basis. 	<p>AC-2 AC-3 AC-5 AC-6 AC-14 AC-16 AC-24</p>

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
	<ul style="list-style-type: none"> ▪ Ability to apply least privilege to user accounts. <ul style="list-style-type: none"> ○ Ability to create additional processes, roles (e.g., admin, emergency, temporary) and accounts as necessary to achieve least privilege. ○ Ability to apply least privilege settings within the device (i.e., to ensure that the processes operate at privilege levels no higher than necessary to accomplish required functions). ○ Ability to limit access to privileged device settings that are used to establish and administer authorization requirements. ○ Ability for authorized users to access privileged settings. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to enable automation and reporting of account management activities. ▪ Ability to establish conditions for shared/group accounts on the IoT device. ▪ Ability to administer conditions for shared/group accounts on the IoT device. ▪ Ability to restrict the use of shared/group accounts on the IoT device according to organizationally defined conditions. ▪ Ability to implement dynamic access control approaches (e.g., service-oriented architectures) that rely on: <ul style="list-style-type: none"> ○ run-time access control decisions facilitated by dynamic privilege management. ○ organizationally defined actions to access/use device. ▪ Ability to allow information sharing capabilities based upon the type and/or role of the user attempting to share the information. 	<ul style="list-style-type: none"> ▪ Providing detailed instructions for how to implement management and operational controls based on the role of the IoT device user, and not on an individual basis. ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing a detailed description of the other types of devices and systems that will access the IoT device during customer use of the device, and how they will access it. ▪ Providing communications and detailed instructions for implementing a hierarchy of privilege levels to use with the IoT device and/or necessary associated information systems. ▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing education explaining how to establish and enforce approved authorizations for logical access to IoT device information and system resources. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level. ▪ Providing education and supporting materials explaining how to establish roles and responsibilities for IoT device data security, using the device capabilities and/or other services that communicate or interface with the device. ▪ Providing education and supporting materials describing the IoT device capabilities for role-based controls, and how to establish different roles within the IoT device. 	

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
	<ul style="list-style-type: none"> ▪ Ability to restrict access to IoT device software, hardware, and data based on user account roles, used with proper authentication of the identity of the user to determine type of authorization. ▪ Ability to establish limits on authorized concurrent device sessions. ▪ Ability to restrict updating actions to authorized entities. ▪ Ability to restrict access to the cybersecurity state indicator to authorized entities. ▪ Ability to revoke access to the IoT device. 	<ul style="list-style-type: none"> ▪ Providing education and supporting materials for how to establish roles to support IoT device policies, procedures, and associated documentation. 	
<p>PR.AC-7: Users, devices, and other assets are authenticated (e.g., single-factor, multi-factor) commensurate with the risk of the transaction (e.g., individuals’ security and privacy risks and other organizational risks).</p>	<ul style="list-style-type: none"> ▪ Ability for the IoT device to require authentication prior to connecting to the device. ▪ Ability for the IoT device to support a second, or more, authentication method(s) such as: <ul style="list-style-type: none"> ○ temporary passwords or other one-use log-on credentials ○ third-party credential checks ○ biometrics ○ hard tokens ▪ Ability to authenticate external users and systems. ▪ Ability to verify and authenticate any update before installing it. 	<ul style="list-style-type: none"> ▪ Providing detailed instructions and guidance for establishing activities performed by the IoT device that do not require identification or authentication. ▪ Providing documentation describing the specific IoT platforms used with the device to support required IoT authentication control techniques. ▪ Providing documentation with details describing external authentication by IoT platforms and associated authentication methods that can be used with the IoT device. 	<p>AC-7 AC-8 AC-9 AC-12 AC-14 IA-2 IA-3 IA-4 IA-5 IA-8 IA-11</p>
<p>PR.DS-1: Data-at-rest is protected.</p>	<ul style="list-style-type: none"> ▪ Ability to execute cryptographic mechanisms of appropriate strength and performance. ▪ Ability to obtain and validate certificates. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to change keys securely. ▪ Ability to generate key pairs. ▪ Ability to store encryption keys securely. ▪ Ability to cryptographically store passwords at rest, as well as device identity and other authentication data. ▪ Ability to support data encryption and signing to prevent data from being altered in device storage. ▪ Ability to secure data stored locally on the device. 	<ul style="list-style-type: none"> ▪ Providing detailed instructions for how to implement management and operational controls for securely handling and retaining IoT device data, associated systems data, and data output from the IoT device. ▪ Providing education describing how to securely handle and retain IoT device data, associated systems data, and data output from the IoT device to meet requirements of the IoT device customers’ organizational security policies, contractual requirements, applicable Federal laws, Executive Orders, directives, policies, regulations, standards, and other legal requirements. 	<p>SC-28 MP-2 MP-4 MP-5</p>

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
	<ul style="list-style-type: none"> ▪ Ability to secure data stored in remote storage areas (e.g., cloud, server). ▪ Ability to utilize separate storage partitions for system and user data. ▪ Ability to protect the audit information through mechanisms such as: <ul style="list-style-type: none"> ○ encryption ○ digitally signing audit files ○ securely sending audit files to another device ○ other protections created by the device manufacturer 		
<p>PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity.</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. 	<p>SC-16 SI-7 MP-4 MP-5</p>
<p>PR.IP-4: Backups of information are conducted, maintained, and tested.</p>	<p>N/A</p>	<ul style="list-style-type: none"> ▪ Providing education to IoT device customers covering the instructions and details necessary for them to create accurate backups and to recover the backups when necessary. 	<p>CP-4 CP-9</p>

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
		<ul style="list-style-type: none"> ▪ Providing education to IoT device customers that includes instructions describing how to back up data from systems where IoT device data is stored. ▪ Providing awareness reminders and tips to IoT device customers (e.g., directly in person, in videos, in an online webinar) for various aspects involved with backing up the IoT device data. 	
<p>PR.MA-1: Maintenance and repair of organizational assets are performed and logged, with approved and controlled tools.</p>	<p>N/A</p>	<ul style="list-style-type: none"> ▪ Providing details about the types of, and situations that trigger, local and/or remote maintenance activities required once the device is purchased and deployed in the organization’s digital ecosystem or within an individual consumer’s home. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing other information and actions as necessary for physically securing, and securely using, the IoT device based upon the IoT device use, purpose, and other contextual factors related to the digital ecosystem(s) within which they are intended to be used. ▪ Providing the details necessary for IoT device customers to implement only organizationally approved IoT device diagnostic tools within their system. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. If such comprehensive IoT device maintenance operations documentation does not exist, the manufacturer should 	<p>MA-2 MA-3 MA-5 MA-6</p>

<i>Cybersecurity Framework v1.1 Subcategory</i>	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
		<p>clearly communicate to IoT device customers that the user must perform these operations themselves.</p> <ul style="list-style-type: none"> ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing the details necessary to enable IoT device customers to monitor onsite and offsite IoT device maintenance activities. ▪ Providing the details necessary to implement management and operational controls for IoT device maintenance personnel and associated authorizations, and record-keeping of maintenance organizations and personnel. ▪ Providing communications describing the type and nature of the local and/or remote maintenance activities that will involve and require manufacturer personnel, or their contractors, once the device is purchased and deployed in the IoT device customer’s organization. ▪ Providing IoT device customers with the details necessary to implement management and operational controls in support of their security policies and legal requirements for IoT device maintenance for assigned organizationally defined personnel or roles to follow. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing the details necessary for customers to document attempts to obtain IoT device components or IoT device information system service documentation when such documentation is either unavailable or nonexistent, and documenting the appropriate response for manufacturer employees, or supporting entities, to follow. ▪ Providing a process for IoT device customers to contact the manufacturer to ask questions or obtain help related to the IoT device configuration settings. 	

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
		<ul style="list-style-type: none"> ▪ Providing information to allow for in-house support from within the IoT device customer organization. ▪ Providing education explaining how to inspect IoT device and/or use maintenance tools to ensure the latest software updates and patches are installed. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing education that explains the legal requirements governing IoT device maintenance responsibilities or how to meet specific types of legal requirements when using the IoT device. 	
<p>PR.MA-2: Remote maintenance of organizational assets is approved, logged, and performed in a manner that prevents unauthorized access.</p>	<p>N/A</p>	<ul style="list-style-type: none"> ▪ Providing details about the types of, and situations that trigger, local and/or remote maintenance activities required once the device is purchased and deployed in the organization’s digital ecosystem or within an individual consumer’s home. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing other information and actions as necessary for physically securing, and securely using, the IoT device based upon the IoT device use, purpose, and other contextual factors related to the digital ecosystem(s) within which they are intended to be used. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing the details necessary to enable IoT device customers to monitor onsite and offsite IoT device maintenance activities. 	<p>MA-4</p>

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
		<ul style="list-style-type: none"> ▪ Providing the details necessary for maintaining records for nonlocal IoT device maintenance and diagnostic activities. ▪ Providing the details necessary to implement management and operational controls for IoT device maintenance personnel and associated authorizations, and record-keeping of maintenance organizations and personnel. ▪ Providing communications describing the type and nature of the local and/or remote maintenance activities that will involve and require manufacturer personnel, or their contractors, once the device is purchased and deployed in the IoT device customer’s organization. ▪ Providing IoT device customers with the details necessary to implement management and operational controls in support of their security policies and legal requirements for IoT device maintenance for assigned organizationally defined personnel or roles to follow. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. 	
DE.AE-1: A baseline of network operations and expected data flows for users and systems is established and managed.	N/A	<ul style="list-style-type: none"> ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. 	AC-4 CA-3 CM-2 SI-4
DE.AE-2: Detected events are analyzed to understand attack targets and methods.	N/A	<ul style="list-style-type: none"> ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. 	AU-6 CA-7 IR-4 SI-4
DE.AE-3: Event data are collected and correlated from multiple sources and sensors.	<ul style="list-style-type: none"> ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). 	<ul style="list-style-type: none"> ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. 	AU-6 AU-12 CA-7 IR-4 IR-5

<i>Cybersecurity Framework v1.1 Subcategory</i>	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	NIST SP 800-53 Rev. 5
DE.CM-1: The information system and assets are monitored to identify cybersecurity events and verify the effectiveness of protective measures.	<ul style="list-style-type: none"> ▪ Ability to keep an accurate internal system time. ▪ Ability to monitor specific actions based on the IoT device identity. ▪ Ability to access information about the IoT device's cybersecurity state and other necessary data. ▪ Ability to monitor for organizationally defined cybersecurity events (e.g., expected state change) that may occur on or involving the IoT device. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. (The device may be able to perform this check itself or provide the information necessary for an external process to check). ▪ Ability to monitor communications traffic. 	<ul style="list-style-type: none"> ▪ Providing information that describes the types of system monitoring information generated from, or associated with, the IoT device and instructions for obtaining that information. ▪ Providing documentation describing the types of monitoring tools with which the IoT device is compatible, and recommendations for how to configure the IoT device to best work with such monitoring tools. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing how to perform monitoring activities. 	SI-4 AU-12 CA-7 CM-3 SC-7 SI-4
DE.CM-3: Personnel activity is monitored to detect potential cybersecurity events.	N/A	N/A	AC-2 AU-12 CA-7 CM-3 SC-5 SC-7 SI-4
DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed.	<ul style="list-style-type: none"> ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. (The device may be able to perform this check itself or provide the information necessary for an external process to check). ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer's supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device. 	AC-2 AU-12 AU-13 CA-7 CM-10 CM-11

E.2 Device Capabilities Supporting Functional Test Scenarios

In this project, the focus was on the engineering workstations and not on the manufacturing components. It is acknowledged that many of the **device cybersecurity capabilities** may not be available in modern sensors and actuators and that other system elements (e.g., proxies, gateways) or other risk mitigation strategies (e.g., network segmentation) may be necessary.

Table E-2 builds on the functional test scenarios included in [Section 5](#) of this document. The table lists both **device cybersecurity capabilities** and **nontechnical supporting capabilities** that map to relevant CSF Subcategories for each of the functional test scenarios. If IoT devices are integrated into future efforts or a production ICS environment, selecting devices and/or third parties that provide these capabilities can help achieve the respective functional requirements.

It is acknowledged that IoT devices vary in their capabilities, and there may not be a clear delineation between the **device cybersecurity capabilities** that are provided by the IoT devices and those provided by another system component. It is also understood that the capabilities of cyber-physical components are evolving, so many of the mappings are not necessarily exact.

In this project, the focus was on the engineering workstations and not on the manufacturing components. It is acknowledged that many of the **device cybersecurity capabilities** may not be available in modern sensors and actuators and that other system elements (e.g., proxies, gateways) or other risk mitigation strategies (e.g., network segmentation) may be necessary.

Table E-2 Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities that Map to Each of the Functional Test Scenarios

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>Scenario 1: Protect Host from Malware via USB: This test will demonstrate blocking the introduction of malware through physical access to a workstation within the manufacturing system.</p> <p>PR.DS-6 PR.MA-2 DE.AE-2</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<p>(e.g., digital signatures, checksums, certificate validation).</p> <ul style="list-style-type: none"> ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). 	<ul style="list-style-type: none"> ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing the details necessary to enable IoT device customers to monitor onsite and offsite IoT device maintenance activities. ▪ Providing communications describing the type and nature of the local and/or remote maintenance activities that will involve and require manufacturer personnel, or their contractors, once the device is purchased and deployed in the IoT device customer’s organization. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched.
<p>Scenario 2: Protect Host from Malware via Network Vector: This test will demonstrate the detection of malware introduction from the network.</p> <p>PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.
<p>Scenario 3: Protect Host from Malware via Remote Access Connections: This test will demonstrate blocking malware attempting to infect</p>	<ul style="list-style-type: none"> ▪ Ability to uniquely identify the IoT device logically. ▪ Ability to uniquely identify a remote IoT device. ▪ Ability for the device to support a unique device ID. ▪ Ability to configure IoT device access control policies using IoT device identity. 	<ul style="list-style-type: none"> ▪ Providing details for how to establish unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing the details necessary to establish and implement unique identification for each IoT device associated with the system and critical system components within which it is used.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>manufacturing system through authorized remote access connections.</p> <p>PR.AC-1 PR.AC-3 PR.AC-4 PR.AC-7 PR.MA-1 PR.MA-2 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to verify the identity of an IoT device. ▪ Ability to add a unique physical identifier at an external or internal location on the device authorized entities can access. ▪ Ability to set and change authentication configurations, policies, and limitations settings for the IoT device. ▪ Ability to revoke access to the device. ▪ Ability to create unique IoT device user accounts. ▪ Ability to identify unique IoT device user accounts. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to authenticate external users and systems. ▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface. ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability to assign roles to IoT device user accounts. 	<ul style="list-style-type: none"> ▪ Providing the tools, assistance, instructions, and other types of information to support establishing a hierarchy of role-based privileges within the IoT device. ▪ Providing details about the specific types of manufacturer’s needs to access the IoT device interfaces, such as for specific support, updates, ongoing maintenance, and other purposes. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level. ▪ Providing detailed instructions and guidance for establishing activities performed by the IoT device that do not require identification or authentication. ▪ Providing documentation describing the specific IoT platforms used with the device to support required IoT authentication control techniques. ▪ Providing documentation with details describing external authentication by IoT platforms and associated authentication methods that can be used with the IoT device. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing details about the types of, and situations that trigger, local and/or remote maintenance activities required once the device is purchased and deployed in the organization’s digital ecosystem or within an individual consumer’s home. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to support a hierarchy of logical access privileges for the IoT device based on roles. ▪ Ability to apply least privilege to user accounts. ▪ Ability to enable automation and reporting of account management activities. ▪ Ability for the IoT device to require authentication prior to connecting to the device. ▪ Ability for the IoT device to support a second, or more, authentication method(s). ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	
<p>Scenario 4: Protect Host from Unauthorized Application Installation: This test will demonstrate blocking the installation and execution of unauthorized</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>applications on workstation in the manufacturing system.</p> <p>PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<p>controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity.</p> <ul style="list-style-type: none"> ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>Scenario 5: Protect from Unauthorized Addition of a Device: This test will demonstrate the detection of an unauthorized device connecting to the manufacturing system.</p> <p>PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.
<p>Scenario 6: Detect Unauthorized Device-to-Device Communications: This test will demonstrate the detection of unauthorized communications between devices.</p> <p>PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<p>(e.g., where its auditing information can be checked to allow for review, analysis, and reporting).</p> <ul style="list-style-type: none"> ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.
<p>Scenario 7: Protect from Unauthorized Modification and Deletion of Files: This test will demonstrate protection of files from unauthorized deletion both locally and on network file share. PR.DS-1 PR.DS-6 PR.IP-4 PR.MA-1</p>	<ul style="list-style-type: none"> ▪ Ability to execute cryptographic mechanisms of appropriate strength and performance. ▪ Ability to obtain and validate certificates. ▪ Ability to change keys securely. ▪ Ability to generate key pairs. ▪ Ability to store encryption keys securely. ▪ Ability to cryptographically store passwords at rest, as well as device identity and other authentication data. ▪ Ability to support data encryption and signing to prevent data from being altered in device storage. ▪ Ability to secure data stored locally on the device. 	<ul style="list-style-type: none"> ▪ Providing detailed instructions for how to implement management and operational controls for securely handling and retaining IoT device data, associated systems data, and data output from the IoT device. ▪ Providing education describing how to securely handle and retain IoT device data, associated systems data, and data output from the IoT device to meet requirements of the IoT device customers’ organizational security policies, contractual requirements, applicable Federal laws, Executive Orders, directives, policies, regulations, standards, and other legal requirements. ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>DE.AE-2</p>	<ul style="list-style-type: none"> ▪ Ability to secure data stored in remote storage areas (e.g., cloud, server). ▪ Ability to utilize separate storage partitions for system and user data. ▪ Ability to protect the audit information through mechanisms such as: <ul style="list-style-type: none"> ○ encryption ○ digitally signing audit files ○ securely sending audit files to another device ○ other protections created by the device manufacturer ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). 	<ul style="list-style-type: none"> ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing education to IoT device customers covering the instructions and details necessary for them to create accurate backups and to recover the backups when necessary. ▪ Providing education to IoT device customers that includes instructions describing how to back up data from systems where IoT device data is stored. ▪ Providing awareness reminders and tips to IoT device customers (e.g., directly in person, in videos, in an online webinar) for various aspects involved with backing up the IoT device data. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>Scenario 8: Detect Unauthorized Modification of PLC Logic: This test will demonstrate the detection of PLC logic modification.</p> <p>PR.AC-3 PR.AC-7 PR.DS-6 PR.MA-1 PR.MA-2 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to authenticate external users and systems. ▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface. ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability for the IoT device to require authentication prior to connecting to the device. ▪ Ability for the IoT device to support a second, or more, authentication method(s). ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. 	<ul style="list-style-type: none"> ▪ Providing detailed instructions and guidance for establishing activities performed by the IoT device that do not require identification or authentication. ▪ Providing documentation describing the specific IoT platforms used with the device to support required IoT authentication control techniques. ▪ Providing documentation with details describing external authentication by IoT platforms and associated authentication methods that can be used with the IoT device. ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing the details necessary to enable IoT device customers to monitor onsite and offsite IoT device maintenance activities. ▪ Providing communications describing the type and nature of the local and/or remote maintenance activities that will involve and require manufacturer personnel, or their contractors, once the device is purchased and deployed in the IoT device customer’s organization. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.
<p>Scenario 9: Protect from Modification of Historian Data:</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>This test will demonstrate the blocking of modification of historian archive data.</p> <p>PR.DS-6 PR.MA-1 DE.AE-2</p>	<ul style="list-style-type: none"> ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). 	<ul style="list-style-type: none"> ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched.
<p>Scenario 10: Detect Sensor Data Manipulation: This test will demonstrate</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. 	<ul style="list-style-type: none"> ▪ Providing education to IoT device customers covering the instructions and details necessary for them to create accurate backups and to recover the backups when necessary. ▪ Providing education to IoT device customers that includes instructions describing how to back up data from systems where IoT device data is stored.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
<p>detection of atypical data reported to the historian.</p> <p>PR.IP-4 PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. 	<ul style="list-style-type: none"> ▪ Providing awareness reminders and tips to IoT device customers (e.g., directly in person, in videos, in an online webinar) for various aspects involved with backing up the IoT device data. ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs. ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.
<p>Scenario 11: Detect Unauthorized Firmware Modification: This test will demonstrate the detection of device firmware modification</p> <p>PR.DS-6 PR.MA-1 DE.AE-1 DE.AE-2 DE.AE-3 DE.CM-1 DE.CM-3 DE.CM-7</p>	<ul style="list-style-type: none"> ▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory). 	<ul style="list-style-type: none"> ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity. ▪ Providing instructions and documentation describing the physical and logical access capabilities necessary to the IoT device to perform each type of maintenance activity. ▪ Providing detailed documentation describing the tools manufacturers require for IoT device diagnostics activities. ▪ Providing the details and instructions to perform necessary IoT device maintenance activities and repairs.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	<ul style="list-style-type: none"> ▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present). 	<ul style="list-style-type: none"> ▪ Providing communications and comprehensive documentation describing the IoT device maintenance operations performed by the manufacturer and the manufacturer’s supporting entities. ▪ Providing communications and comprehensive documentation describing maintenance operations that the IoT device customer is required to perform. ▪ Providing communications that include details for the recommended events that will trigger IoT device system reviews and/or maintenance by the manufacturer. ▪ Providing communications and documentation detailing how to perform recommended local and/or remote maintenance activities. ▪ Providing documented descriptions of the specific maintenance procedures for defined maintenance tasks. ▪ Providing education for how to scan for critical software updates and patches. ▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.

DRAFT

NIST SPECIAL PUBLICATION 1800-10C

Protecting Information and System Integrity in Industrial Control System Environments: Cybersecurity for the Manufacturing Sector

Volume C:
How-To Guides

Michael Powell

National Cybersecurity Center of Excellence
National Institute of Standards and Technology

Joseph Brule*

Cyber Security Directorate
National Security Agency

Michael Pease

Keith Stouffer

CheeYee Tang

Timothy Zimmerman

Engineering Laboratory
National Institute of Standards and Technology

Chelsea Deane

John Hoyt

Mary Raguso

Aslam Sherule

Kangmin Zheng

The MITRE Corporation
McLean, Virginia

Matthew Zopf

Stratavia

Largo, Maryland

*Former employee; all work for this publication done while at employer.

September 2021

DRAFT

This publication is available free of charge from <https://www.nccoe.nist.gov/projects/use-cases/manufacturing/integrity-ics>



1 **DISCLAIMER**

2 Certain commercial entities, equipment, products, or materials may be identified in this document in
3 order to describe an experimental procedure or concept adequately. Such identification is not intended
4 to imply special status or relationship with NIST or recommendation or endorsement by NIST or NCCoE;
5 neither is it intended to imply that entities, equipment, products, or materials are necessarily the best
6 available for the purpose.

7 While NIST and the NCCoE address goals of improving management of cybersecurity and privacy risk
8 through outreach and application of standards and best practices, it is the stakeholder's responsibility to
9 fully perform a risk assessment to include the current threat, vulnerabilities, likelihood of a compromise,
10 and the impact should the threat be realized before adopting cybersecurity measures such as this
11 recommendation.

12 Domain name and IP addresses shown in this guide represent an example domain and network
13 environment to demonstrate the NCCoE project use case scenarios and the security capabilities.

14 National Institute of Standards and Technology Special Publication 1800-10C, Natl. Inst. Stand. Technol.
15 Spec. Publ. 1800-10C, 128 pages, September 2021

16 **FEEDBACK**

17 You can improve this guide by contributing feedback. As you review and adopt this solution for your
18 own organization, we ask you and your colleagues to share your experience and advice with us.

19 Comments on this publication may be submitted to: manufacturing_nccoe@nist.gov.

20 Public comment period: September 23, 2021 through November 07, 2021

21 All comments are subject to release under the Freedom of Information Act (FOIA).

22 National Cybersecurity Center of Excellence
23 National Institute of Standards and Technology
24 100 Bureau Drive
25 Mailstop 2002
26 Gaithersburg, MD 20899
27 Email: nccoe@nist.gov

28 **NATIONAL CYBERSECURITY CENTER OF EXCELLENCE**

29 The National Cybersecurity Center of Excellence (NCCoE), a part of the National Institute of Standards
30 and Technology (NIST), is a collaborative hub where industry organizations, government agencies, and
31 academic institutions work together to address businesses' most pressing cybersecurity issues. This
32 public-private partnership enables the creation of practical cybersecurity solutions for specific
33 industries, as well as for broad, cross-sector technology challenges. Through consortia under
34 Cooperative Research and Development Agreements (CRADAs), including technology partners—from
35 Fortune 50 market leaders to smaller companies specializing in information technology security—the
36 NCCoE applies standards and best practices to develop modular, easily adaptable example cybersecurity
37 solutions using commercially available technology. The NCCoE documents these example solutions in
38 the NIST Special Publication 1800 series, which maps capabilities to the NIST Cybersecurity Framework
39 and details the steps needed for another entity to re-create the example solution. The NCCoE was
40 established in 2012 by NIST in partnership with the State of Maryland and Montgomery County,
41 Maryland.

42 To learn more about the NCCoE, visit <https://www.nccoe.nist.gov/>. To learn more about NIST, visit
43 <https://www.nist.gov>

44 **NIST CYBERSECURITY PRACTICE GUIDES**

45 NIST Cybersecurity Practice Guides (Special Publication 1800 series) target specific cybersecurity
46 challenges in the public and private sectors. They are practical, user-friendly guides that facilitate the
47 adoption of standards-based approaches to cybersecurity. They show members of the information
48 security community how to implement example solutions that help them align more easily with relevant
49 standards and best practices, and provide users with the materials lists, configuration files, and other
50 information they need to implement a similar approach.

51 The documents in this series describe example implementations of cybersecurity practices that
52 businesses and other organizations may voluntarily adopt. These documents do not describe regulations
53 or mandatory practices, nor do they carry statutory authority.

54 **ABSTRACT**

55 Today's manufacturing organizations rely on industrial control systems (ICS) to conduct their operations.
56 Increasingly, ICS are facing more frequent, sophisticated cyber attacks—making manufacturing the
57 second-most targeted industry (C. Singleton et al., X-Force Threat Intelligence Index 2021, IBM, February
58 2021, <https://www.ibm.com/security/data-breach/threat-intelligence>). Cyber attacks against ICS
59 threaten operations and worker safety, resulting in financial loss and harm to the organization's
60 reputation.

61 The architecture and solutions presented in this guide are built upon standards-based, commercially
62 available products, and represent some of the possible solutions. The solutions implement standard
63 cybersecurity capabilities, such as behavioral anomaly detection, application allowlisting, file integrity-
64 checking, change control management, and user authentication and authorization. The solution was
65 tested in two distinct lab settings: a discrete manufacturing work cell, which represents an assembly line

66 production, and a continuous process control system, which represents chemical manufacturing
 67 industries.

68 Organizations that are interested in protecting the integrity of the manufacturing system and
 69 information from destructive malware, insider threats, and unauthorized software should first conduct a
 70 risk assessment and determine the appropriate security capabilities required to mitigate those risks.
 71 Once the security capabilities are identified, the sample architecture and solution presented in this
 72 document may be used.

73 The security capabilities of the example solution are mapped to NIST’s Cybersecurity Framework, the
 74 National Initiative for Cybersecurity Education Framework, and NIST Special Publication 800-53.

75 **KEYWORDS**

76 *Manufacturing; industrial control systems; application allowlisting; file integrity checking; user*
 77 *authentication; user authorization; behavioral anomaly detection; remote access; software modification;*
 78 *firmware modification.*

79 **ACKNOWLEDGEMENTS**

80 We are grateful to the following individuals for their generous contributions of expertise and time.

Name	Organization
Dan Frechette	Microsoft
Ian Schmertzler	Dispel
Ben Burke	Dispel
Chris Jensen	Tenable
Bethany Brower	VMWare
Dennis Hui	OSIsoft (now part of AVEVA)
John Matranga	OSIsoft (now part of AVEVA)
Michael A. Piccalo	Forescout
Tim Jones	Forescout
Yejin Jang	Forescout
Samantha Pelletier	TDI Technologies
Rusty Hale	TDI Technologies
Steve Petruzzo	GreenTec-USA
Josh Carlson	Dragos
Alex Baretta	Dragos

81 The Technology Partners/Collaborators who participated in this build submitted their products in
 82 response to a notice in the Federal Register. Respondents with relevant products were invited to sign a

83 Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in
 84 a consortium to build this example solution. The participants in this project were:

Technology Partner/Collaborator	Product
Carbon Black (VMware)	Carbon Black App Control
Microsoft	Azure Defender for the internet of things (IoT) (incorporating technology from the acquisition of CyberX)
Dispel	Dispel Wicket ESI Dispel Enclave Dispel VDI (Virtual Desktop Interface)
Dragos	Dragos Platform
Forescout	eyeInspect (Formerly SilentDefense) ICS Patrol EyeSight
GreenTec	WORMdisk and ForceField
OSIsoft (now part of AVEVA)	PI System (which comprises products such as PI Server, PI Vision and others)
TDi Technologies	ConsoleWorks
Tenable	Tenable.ot

85 DOCUMENT CONVENTIONS

86 The terms “shall” and “shall not” indicate requirements to be followed strictly to conform to the
 87 publication and from which no deviation is permitted. The terms “should” and “should not” indicate that
 88 among several possibilities, one is recommended as particularly suitable without mentioning or
 89 excluding others, or that a certain course of action is preferred but not necessarily required, or that (in
 90 the negative form) a certain possibility or course of action is discouraged but not prohibited. The terms
 91 “may” and “need not” indicate a course of action permissible within the limits of the publication. The
 92 terms “can” and “cannot” indicate a possibility and capability, whether material, physical, or causal.

93 CALL FOR PATENT CLAIMS

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

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

102 a) assurance in the form of a general disclaimer to the effect that such party does not hold and does not
103 currently intend holding any essential patent claim(s); or

104 b) assurance that a license to such essential patent claim(s) will be made available to applicants desiring
105 to utilize the license for the purpose of complying with the guidance or requirements in this ITL draft
106 publication either:

107 1. under reasonable terms and conditions that are demonstrably free of any unfair discrimination;
108 or

109 2. without compensation and under reasonable terms and conditions that are demonstrably free
110 of any unfair discrimination.

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

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

118 Such statements should be addressed to: manufacturing_nccoe@nist.gov

119	Contents	
120	1 Introduction	1
121	1.1 How to Use this Guide.....	1
122	1.1 Build Overview	2
123	1.2 Typographic Conventions.....	2
124	1.3 Logical Architecture Summary	3
125	2 Product Installation Guides	5
126	2.1 Dispel Remote Access.....	5
127	2.1.1 Host and Network Configuration.....	6
128	2.1.2 Installation	7
129	2.1.3 Configuration	8
130	2.2 Dragos.....	12
131	2.2.1 Host and Network Configuration.....	12
132	2.2.2 Installation	13
133	2.2.3 Configuration	13
134	2.3 Forescout Platform.....	17
135	2.3.1 Host and Network Configuration.....	19
136	2.3.2 Installation	20
137	2.3.3 Configuration	22
138	2.4 GreenTec-USA	31
139	2.4.1 Host and Network Configuration.....	32
140	2.4.2 Installation	32
141	2.4.3 Configuration	33
142	2.5 Microsoft Azure Defender for IoT	36
143	2.5.1 Host and Network Configuration.....	36
144	2.5.2 Installation	36
145	2.5.3 Configuration	36
146	2.6 OSIsoft PI Data Archive.....	41
147	2.6.1 Host and Network Configuration.....	41
148	2.6.2 Installation	42
149	2.6.3 Configuration	43
150	2.7 Security Onion	64
151	2.7.1 Host and Network Configuration.....	64

152	2.7.2	Installation	65
153	2.7.3	Configuration	65
154	2.8	TDi ConsoleWorks	68
155	2.8.1	Host and Network Configuration	68
156	2.8.2	Installation	68
157	2.8.3	Configuration	75
158	2.9	Tenable.OT	97
159	2.9.1	Host and Network Configuration	97
160	2.9.2	Installation	97
161	2.9.3	Configuration	97
162	2.10	VMware Carbon Black App Control.....	105
163	2.10.1	Host and Network Configuration	105
164	2.10.2	Installation	106
165	2.10.3	Configuration	107
166	2.11	Windows Software Restriction Policy	114
167	2.11.1	Host and Network Configuration	114
168	2.11.2	Installation	115
169	2.11.3	Configuration	115
170	Appendix A	List of Acronyms	123
171	Appendix B	Build Architectures Diagrams	125

172	List of Figures	
173	Figure 1-1: CSMS Network Architecture	4
174	Figure 2-1 Dispel High-level Implementation, from Remote Access for ICS	6
175	Figure 2-2 Mapping a Network Drive	11
176	Figure 2-3 Authentication to File Server	12
177	Figure 2-4 Dragos OSIssoft PI Server Integration	13
178	Figure 2-5 Dragos PI Web API Configuration.....	14
179	Figure 2-6 OSIssoft PI Server to Dragos Asset and Data Pairing.....	15
180	Figure 2-7 OSIssoft PI Server and Dragos Paired Data Elements.....	15
181	Figure 2-8 Dragos Zone Administration Page.....	16
182	Figure 2-9 Dragos Create Zone Pop-up	17
183	Figure 2-10 Forescout High-Level Components and Dataflows	18
184	Figure 2-11 Forescout SecureConnector Distribution Tool	21
185	Figure 2-12 Forescout Agent Download	21
186	Figure 2-13 eyeInspect Sensor Admin/Overview Page – Add Sensor	22
187	Figure 2-14 Adding a New SilentDefense Sensor Dialog	23
188	Figure 2-15 eyeInspect ICMP Protocol/Port Scan Attempt Settings	24
189	Figure 2-16 eyeInspect Sensor Configuration Options.....	24
190	Figure 2-17 eyeInspect Portscan Detection Settings	25
191	Figure 2-18 Add ICS Patrol Sensor Dialog	26
192	Figure 2-19 ICS Patrol Sensor Admin Page.....	27
193	Figure 2-20 Add an ICS Patrol Scan Policy.....	28
194	Figure 2-21 eyeSight Add Dialog – General Information.....	29
195	Figure 2-22 eyeSight Add – Command Center Credentials.....	30
196	Figure 2-23 eyeSight OT Settings.....	31
197	Figure 2-24 eyeSight Test Connection Successful Message.....	31
198	Figure 2-25 Azure Defender for IoT SSH Session for Network Configuration	37
199	Figure 2-26 Azure Defender for IoT Create New Data Mining Report for AMS Protocol Information ...	38
200	Figure 2-27 Azure Defender for IoT Custom Alert for Firmware Major Version Number Change.....	39
201	Figure 2-28 Azure Defender for IoT Custom Alert for Firmware Minor Version Number Change.....	40
202	Figure 2-29 Azure Defender for IoT Custom Alert for Firmware Build Version Number Change	40

203 **Figure 2-30 Screenshot of the PI Interface Configuration Utility before the Interface is configured.44**

204 **Figure 2-31 Screenshot of the PI Data Collection Manager Displaying Green Checkmarks After the PI**
205 **System Connector is Properly Configured45**

206 **Figure 2-32 Screenshot of the PI Interface Configuration Utility Showing the Added Scan Class # 2 for**
207 **Polling the PLC Every 60 Seconds54**

208 **Figure 2-33 Screenshot of the PI System Management Tools Component After Configuring the PI**
209 **Points for PLC Hardware and Firmware Version Number Integrity Checking.....56**

210 **Figure 2-34 Screenshot of PI System Explorer Displaying some Attributes of the PLC Element.**
211 **Attributes for the TwinCAT version number are visible in the list.59**

212 **Figure 2-35 Screenshot of PI System Explorer Displaying the Hardware Serial Number Mismatch Event**
213 **Frame Template.....60**

214 **Figure 2-36 Screenshot of PI System Explorer Displaying the TwinCAT Version Mismatch Event Frame**
215 **Template61**

216 **Figure 2-37 Screenshot of PI System Explorer Displaying the Hardware Serial Number Mismatch**
217 **Analysis Template in the PLC Element Template62**

218 **Figure 2-38 Screenshot of PI System Explorer Displaying the TwinCAT Firmware Version Mismatch**
219 **Analysis Template in the PLC Element Template63**

220 **Figure 2-39 Wazuh Agent Manager66**

221 **Figure 2-40 ossec.conf File.....66**

222 **Figure 2-41 Wazuh Agent Manager User Interface67**

223 **Figure 2-42 Log Received After a File Change Was Detected67**

224 **Figure 2-43 ConsoleWorks Registration Screen73**

225 **Figure 2-44 ConsoleWorks Offline Registration Process73**

226 **Figure 2-45 ConsoleWorks System Backups.....74**

227 **Figure 2-46 ConsoleWorks Importing System Configurations and Components75**

228 **Figure 2-47 ConsoleWorks Password Settings76**

229 **Figure 2-48 ConsoleWorks Add the Local Graphical Gateway for RDP Access77**

230 **Figure 2-49 ConsoleWorks Example Device Type Definition.....79**

231 **Figure 2-50 ConsoleWorks List of Device Types79**

232 **Figure 2-51 ConsoleWorks Example Device Definition80**

233 **Figure 2-52 ConsoleWorks List of PCS (Build 1) Devices81**

234 **Figure 2-53 ConsoleWorks List of CRS (Build 3) Devices82**

235 **Figure 2-54 ConsoleWorks Example RDP Configuration83**

236 **Figure 2-55 ConsoleWorks List of PCS (Build 1) RDP Connections85**

237	Figure 2-56 ConsoleWorks List of CRS (Build 3) RDP Connections	86
238	Figure 2-57 ConsoleWorks Example Console (SSH) Connection	87
239	Figure 2-58 ConsoleWorks Example Console (Web Forward) Connection	88
240	Figure 2-59 ConsoleWorks List of PCS (Build 1) Console Connections	89
241	Figure 2-60 ConsoleWorks List of CRS (Build 3) Console Connections	90
242	Figure 2-61 ConsoleWorks List of Tags for PCS (Build 1)	91
243	Figure 2-62 ConsoleWorks Example Tag Definition Screen	92
244	Figure 2-63 ConsoleWorks Example Profile	95
245	Figure 2-64 Tenable.OT Local Device Setting for NTP Service	98
246	Figure 2-65 Tenable.OT Asset Discovery Settings.....	99
247	Figure 2-66 Tenable.OT Controller Scans.....	100
248	Figure 2-67 Tenable.OT Network Scan Settings	101
249	Figure 2-68 Tenable.OT Create Asset Group Type.....	101
250	Figure 2-69 Tenable.OT Create Asset Group Definition	102
251	Figure 2-70 Tenable.OT Policy Settings	103
252	Figure 2-71 Tenable.OT Create Policy – Event Type Options	103
253	Figure 2-72 Tenable.OT Create Policy - Definition.....	104
254	Figure 2-73 Tenable.OT Create Policy - Actions.....	105
255	Figure 2-74 Excerpt from Carbon Black Documentation on Support Server Requirements	108
256	Figure 2-75 IIS Configuration for Carbon Black, Server Roles.....	109
257	Figure 2-76 Carbon Black Policy Edit	110
258	Figure 2-77 Carbon Black App Control System Configuration	111
259	Figure 2-78 Carbon Black App Control AD Policy Mappings.....	112
260	Figure 2-79 Carbon Black Agent Download.....	113
261	Figure 2-80 Carbon Black App Control Computers	113
262	Figure 2-81 Carbon Black App Control File Catalog	114
263	Figure 2-82 Setting Enforcement Properties.....	117
264	Figure 2-83 Setting Security Level Default	118
265	Figure 2-84 Additional Rules Defined for Lab Environment	119
266	Figure 2-85 Menu Options for Accessing the Link an Existing GPO Option	120
267	Figure 2-86 Dialog Box for Selecting GPO to Link	121

268 **Figure B - 1 Build 1 Architecture Diagram**.....125
269 **Figure B - 2 Build 2 Architecture Diagram**.....126
270 **Figure B - 3 Build 3 Architecture Diagram**.....127
271 **Figure B - 4 Build 4 Architecture Diagram**.....128

272 **List of Tables**

273 **Table 2-1 Dispel Deployment**.....6
274 **Table 2-2 Firewall Rules for Dispel**9
275 **Table 2-3 Firewall Rules**.....10
276 **Table 2-4 Dragos Deployment**12
277 **Table 2-5 Forescout Deployment**19
278 **Table 2-6 eyeSight Agent Deployment**19
279 **Table 2-7 Firewall Rules for Forescout**20
280 **Table 2-8 GreenTec-USA WORMdrive and ForceField Deployment**32
281 **Table 2-9 Microsoft Azure Defender IoT Deployment**36
282 **Table 2-10 OSIssoft PI Domain Hosts Deployment**41
283 **Table 2-11 OSIssoft PI CRS Hosts Deployment**41
284 **Table 2-12 OSIssoft PI PCS Hosts Deployment**.....41
285 **Table 2-13 Security Onion Domain Hosts Deployment**.....64
286 **Table 2-14 Security Onion PCS Hosts Deployment**65
287 **Table 2-15 Security Onion CRS Hosts Deployment**65
288 **Table 2-16 ConsoleWorks Build 1 Deployment**68
289 **Table 2-17 ConsoleWorks Build 3 Deployment**68
290 **Table 2-18 ConsoleWorks Device Type List**.....78
291 **Table 2-19 ConsoleWorks PCS (Build 1) Devices**80
292 **Table 2-20 ConsoleWorks CRS (Build 3) Devices**81
293 **Table 2-21 ConsoleWorks PCS (Build 1) Graphical Connections**84
294 **Table 2-22 ConsoleWorks CRS (Build 3) Graphical Connections**.....86
295 **Table 2-23 ConsoleWorks PCS (Build 1) Console Connections**88
296 **Table 2-24 ConsoleWorks CRS (Build 3) Console Connections**89

297	Table 2-25 Tenable.OT Appliance Details.	97
298	Table 2-26 Firewall Rules for Tenable.OT	97
299	Table 2-27 Carbon Black App Control Domain Hosts Deployment	106
300	Table 2-28 Carbon Black App Control PCS Hosts Deployment	106
301	Table 2-29 Carbon Black App Control CRS Hosts Deployment	106
302	Table 2-30 Windows SRP Domain Servers	114
303	Table 2-31 Windows SRP Build 2 Deployment	115
304	Table 2-32 Windows SRP Build 3 Deployment	115

305 1 Introduction

306 The following volume of this guide show information technology (IT) professionals and security
307 engineers how we implemented this example solution. We cover all the products employed in this
308 reference design. We do not re-create the product manufacturers' documentation, which is presumed
309 to be widely available. Rather, these volumes show how we incorporated the products together in our
310 environment.

311 *Note: These are not comprehensive tutorials. There are many possible service and security configurations*
312 *for these products that are out of scope for this reference design.*

313 1.1 How to Use this Guide

314 This NIST Cybersecurity Practice Guide demonstrates a modular design and provides users with the
315 information they need to replicate the described manufacturing industrial control system (ICS) security
316 solutions, specifically focusing on information and system integrity. This reference design is modular and
317 can be deployed in whole or in part.

318 This guide contains three volumes:

- 319 ▪ NIST SP 1800-10A: *Executive Summary*
- 320 ▪ NIST SP 1800-10B: *Approach, Architecture, and Security Characteristics* – what we built and why
- 321 ▪ NIST SP 1800-10C: *How-To Guides* – instructions for building the example solution (**this**
322 **document**)

323 Depending on your role in your organization, you might use this guide in different ways:

324 **Senior information technology (IT) executives, including chief information security and technology**
325 **officers**, will be interested in the Executive Summary, NIST SP 1800-10A, which describes the following
326 topics:

- 327 ▪ challenges that enterprises face in ICS environments in the manufacturing sector
- 328 ▪ example solution built at the NCCoE
- 329 ▪ benefits of adopting the example solution

330 Technology or security program managers might share the *Executive Summary*, NIST SP 1800-10A, with
331 your leadership to help them understand the importance of adopting a standards-based solution. Doing
332 so can strengthen their information and system integrity practices by leveraging capabilities that may
333 already exist within their operating environment or by implementing new capabilities.

334 **Technology or security program managers** who are concerned with how to identify, understand, assess,
335 and mitigate risk will be interested in *NIST SP 1800-10B*, which describes what we did and why. The
336 following sections will be of particular interest:

- 337 ▪ Section 3.4.1, Security Control Map, maps the security characteristics of this example solution to
338 cybersecurity standards and best practices.
- 339 ▪ IT professionals who want to implement an approach like this will find this whole practice guide
340 useful. You can use this How-To portion of the guide, *NIST SP 1800-10C*, to replicate all or parts

341 of the build created in our lab. This How-To portion of the guide provides specific product
 342 installation, configuration, and integration instructions for implementing the example solution.
 343 We do not recreate the product manufacturers' documentation, which is generally widely
 344 available. Rather, we show how we incorporated the products together in our environment to
 345 create an example solution.

346 This guide assumes that IT professionals have experience implementing security products within the
 347 enterprise. While we have used a suite of commercial products to address this challenge, this guide does
 348 not endorse any products. Your organization can adopt this solution or one that adheres to these
 349 guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of
 350 this manufacturing ICS solution. Your organization's security experts should identify the products that
 351 will best integrate with your existing tools and IT system infrastructure. We hope that you will seek
 352 products that are congruent with applicable standards and best practices. Section 3.5, Technologies, in
 353 *NIST SP 1800-10B*, lists the products that we used and maps them to the cybersecurity controls provided
 354 by this reference solution.

355 A NIST Cybersecurity Practice Guide does not describe "the" solution, but a possible solution. This is a
 356 draft guide. We seek feedback on its contents and welcome your input. Comments, suggestions, and
 357 success stories will improve subsequent versions of this guide. Please contribute your thoughts to
 358 manufacturing_nccoe@nist.gov.

359 1.1 Build Overview

360 The NCCoE partnered with NIST's Engineering Laboratory (EL) to provide real-world scenarios that could
 361 happen in ICS in the manufacturing sector. This collaboration spawned four unique builds: two builds
 362 within the Collaborative Robotics (CRS) environment and two builds within the Process Control System
 363 (PCS) environment. For each build, the NCCoE and the EL performed eleven scenarios. The step-by-step
 364 instructions on how each product was installed and configured in this lab environment are outlined in
 365 this document. For more information on the two environments refer to Section 4.5 in *NIST SP 1800-10B*.
 366 Additionally, Appendix B of this Volume contains the four build architecture diagrams for reference.

367 1.2 Typographic Conventions

368 The following table presents typographic conventions used in this volume.

Typeface/Symbol	Meaning	Example
<i>Italics</i>	file names and path names; references to documents that are not hyperlinks; new terms; and placeholders	For language use and style guidance, see the <i>NCCoE Style Guide</i> .
Bold	names of menus, options, command buttons, and fields	Choose File > Edit .
Monospace	command-line input, on-screen computer output, sample code examples, and status codes	<code>mkdir</code>

Typeface/Symbol	Meaning	Example
Monospace Bold	command-line user input contrasted with computer output	<code>service sshd start</code>
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST’s NCCoE are available at https://www.nccoe.nist.gov .

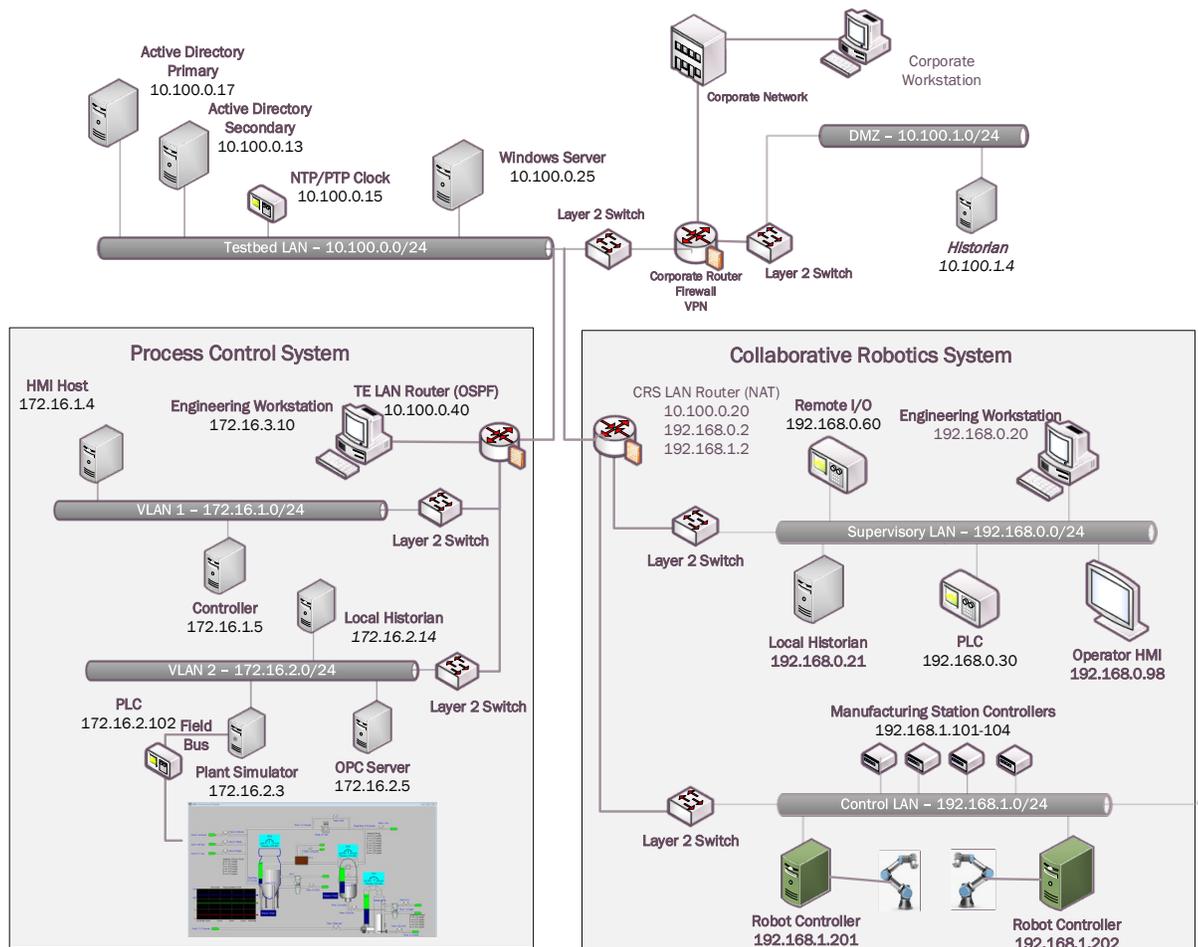
369 1.3 Logical Architecture Summary

370 The security mechanisms and technologies were integrated into the existing NIST Cybersecurity for
 371 Smart Manufacturing Systems (CSMS) lab environment. This cybersecurity performance testbed for ICS
 372 is comprised of the PCS and the CRS environments along with additional networking capabilities to
 373 emulate common manufacturing environments. For more information see *An Industrial Control System
 374 Cybersecurity Performance Testbed*, NISTIR 8089,
 375 <http://nvlpubs.nist.gov/nistpubs/ir/2015/NIST.IR.8089.pdf>.

376 Typically, manufacturing organizations have unique cyber-ecosystems and specific needs for their
 377 operations. To demonstrate the modularity and interoperability of the provided solutions, this project
 378 used available Cooperative Research and Development Agreement (CRADA) partner technologies to
 379 assemble four “builds” deployed across both the PCS and CRS. Additionally, to increase the diversity of
 380 technologies between builds, two of the builds also utilized open source solutions (Security Onion
 381 Wazuh), native operating system features (Windows Software Restriction Policies [SRP]), and a Cisco
 382 Adaptive Security Appliance (ASA) device configured with the AnyConnect VPN client.

383 Figure 1-1 depicts a high-level architecture for the demonstration environment consisting of a Testbed
 384 Local Area Network (LAN), a demilitarized zone (DMZ), the PCS, and the CRS. The environment utilizes a
 385 combination of physical and virtual systems and maintains a local network time protocol (NTP) server
 386 for time synchronization. Additionally, the environment utilizes virtualized Active Directory (AD) servers
 387 for domain services. The tools used to support information and system integrity are deployed and
 388 integrated in the DMZ, Testbed LAN, PCS, and CRS per vendor recommendations and standard practices
 389 as described in the detailed sections for each build.

390 Figure 1-1: CSMS Network Architecture



391 In summary, there are six networks within the CSMS architecture:

392 **Testbed LAN:** This network is where the majority of the collaborators' products are installed. This LAN
 393 has access to the PCS and CRS environments. Other systems, such as AD, an NTP server, and a Windows
 394 server, are also located on this LAN. The Testbed LAN has three gateways to other network segments,
 395 including 10.100.0.1 to reach the DMZ and the corporate network, 10.100.0.20 as a network address
 396 translation (NAT) interface to the CRS environment, and 10.100.0.40 as the gateway to the PCS
 397 environment.

398 **DMZ:** A demilitarized zone that separates the corporate network from the operational technology (OT)
 399 network. Many of the collaborators' products are also installed in the DMZ. The DMZ is used across the
 400 PCS and CRS environments.

401 **PCS Virtual Local Area Network (VLAN) 1:** This is the operations LAN within the PCS environment. This
 402 LAN simulates a central control room environment. The gateway interface for this network segment is
 403 172.16.1.1

404 **PCS VLAN 2:** This is the supervisory LAN within the PCS environment. This LAN simulates the process
 405 operation/manufacturing environment, which consists of the operating plant, programmable logic

406 controller (PLC)s, object linking and embedding for process control (OPC) server, and data historian. The
407 gateway interface for this network segment is 172.16.2.1

408 **CRS Supervisory LAN:** This LAN is within the CRS environment. The historian, PLCs, operating human
409 machine interface (HMI), Engineering workstation, and remote input/output devices are connected to
410 this network. The gateway interface for this network segment is 192.168.0.2

411 **CRS Control LAN:** This LAN is within the CRS environment. The robot controllers and manufacturing
412 station controllers are connected to this network. The gateway interface for this network segment is
413 192.168.1.2

414 The test bed networks used static IPv4 addresses exclusively, and the subnet masks were set to
415 255.255.255.0. No IPv6 addresses were used. This setup is consistent with industry practice. Specific
416 Internet Protocol (IP) addresses are listed for each component in the following sections.

417 For an in-depth view of the architectures PCS and CRS builds, specific build architecture diagrams can be
418 found in Volume B of this practice guide, Section 4.3, Process Control System, and Section 4.4,
419 Collaborative Robotics System.

420 2 Product Installation Guides

421 This section of the practice guide contains detailed instructions for installing and configuring all the
422 products used to build the example solutions.

423 2.1 Dispel Remote Access

424 Dispel is a remote access tool for OT environments that provides secure remote access to the industrial
425 networks. Dispel, implemented in Build 2 and Build 4, uses cloud-based virtual desktop interfaces (VDIs)
426 that traverse a cloud-based Enclave to reach a Wicket ESI device that is deployed within the local OT
427 network. Dispel supports both user authentication and authorization, and remote access for Builds 2
428 and 4.

429 Virtual Desktop Interfaces (VDIs)

430 VDIs are Virtual Machines (VMs) that reside in the cloud and allow users to connect using Remote
431 Desktop Protocol (RDP). The VDIs establish a secure connection to the Wicket ESI located in the OT
432 network to provide network access to the OT devices.

433 Enclave

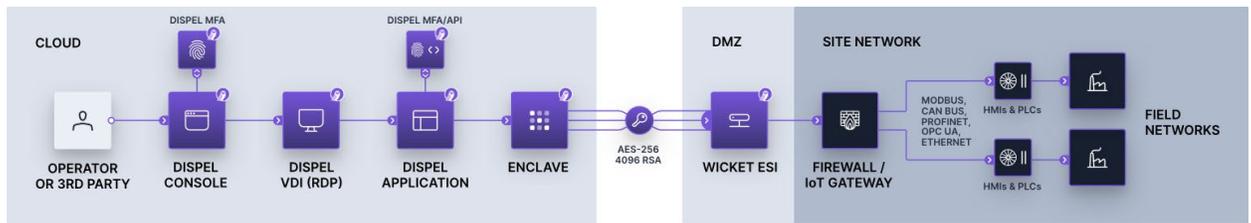
434 Enclaves are single-tenanted, colorless core, moving target defense (MTD) networks. Enclaves are
435 composed of VMs that act as traffic nodes. To create a shifting target profile, these VMs are steadily
436 replaced by new VMs launched on different hypervisors, in different geographic regions, and/or on
437 altogether different public or private clouds. In the case of Builds 2 and 4, the Enclaves were launched
438 exclusively on public clouds. To provide a static set of IP addresses throughout the builds, the MTD
439 characteristic was disabled.

440 **Wicket ESI**

441 Wicket ESIs are on-premise components, shown in Figure 2-1, that allows users to connect to the OT
 442 network remotely. These devices establish encrypted connections from the local OT network up to an
 443 Enclave which, in turn, is connected to the VDI, allowing a remote user to access the OT devices.

444 Additional information is available in *Remote Access for Industrial Control Systems* from Dispel.io at:
 445 [https://s3.amazonaws.com/downloads.dispel.io/resources/One+Pager/dispel-ics-](https://s3.amazonaws.com/downloads.dispel.io/resources/One+Pager/dispel-ics-brochure_20190529.pdf)
 446 [brochure_20190529.pdf](https://s3.amazonaws.com/downloads.dispel.io/resources/One+Pager/dispel-ics-brochure_20190529.pdf)

447 **Figure 2-1 Dispel High-level Implementation, from Remote Access for ICS**



448 **2.1.1 Host and Network Configuration**

449 The Wicket ESI is connected to two ports within the DMZ, one for supporting outbound communications
 450 to the Dispel Enclave (labeled “WAN”) and one for supporting communication through the local firewall
 451 to the ICS environment (labeled “LAN”). The items listed in Table 2-1 are the Wicket ESI specific device
 452 and network settings for the hardware provided to support Build 2 [Figure B-2](#) and 4 [Figure B-4](#).

453 **Table 2-1 Dispel Deployment**

Name	System	OS	CPU	Memory	Storage	Network
Dispel Wicket ESI	ONLOGIC, ML340G-51	Ubuntu 16.04	Intel i5-6300U	16GB	120GB	Wicket WAN Interface 10.100.1.60 Wicket LAN Interface 10.100.1.61 DMZ
Dispel Enclave	Cloud Virtual Machines	Ubuntu 16.04	Variable	Variable	Variable	N/A
Dispel VDI	Cloud Virtual Machine	Windows Server 2016	Intel Xeon Platinum 8171M	8GB	120GB	N/A

454 2.1.2 Installation

455 Installation involves establishing an account on the Dispel cloud-infrastructure and deploying the
 456 preconfigured Wicket ESI device within the OT environment. Detailed installation information,
 457 customized to the end user's deployment, is provided by Dispel.

458 After connecting the WAN and LAN network cables, configuring the Wicket ESI required connecting a
 459 monitor, keyboard, and mouse to the unit using the available VGA and USB ports. Logging into the unit
 460 locally using the credentials provided by Dispel enabled configuration of the network connections using
 461 the following procedure (note: these procedures were executed using root privileges and can also be
 462 performed using Sudo).

- 463 1. Update the network interfaces with the IP configuration information:

464 **#> vi /etc/network/interfaces**

```
source-directory /etc/network/interfaces.d
# LAN
auto enp4s0
allow-hotplug enp4s0
iface enp4s0 inet static
    address 10.100.1.61
    netmask 255.255.255.0
    #gateway
    up route add -net 10.100.0.0 netmask 255.255.255.0 gw 10.100.1.1 dev
enp4s0
    up route add -net 172.16.0.0 netmask 255.255.252.0 gw 10.100.1.1 dev
enp4s0

# WAN
auto enp0s31f6
allow-hotplug enp0s31f6
iface enp0s31f6 inet static
    address 10.100.1.60
    netmask 255.255.255.0
    gateway 10.100.1.1
    dns-nameservers <ip address>
```

- 465 2. Update the Wicket ESI netcutter.cfg file to include the local subnet information (toward the
 466 bottom of the file):

467 **#> vi /home/ubuntu/wicket/netcutter.cfg**

```
...
subnets = (
    {
        name = "Default";
        value = "10.100.0.0/24";
        advertise = "false";
    },
    {
        name = "PCS";
        value = "172.16.0.0/22";
        advertise = "false";
    }
);
```

```

    },
    {
      name = "DMZ";
      value = "10.100.1.0/24";
      advertise = "false";
    });

```

468 3. Restart the Wicket services with the following command:

469 **#> service wicket restart**

470 4. Check the log for errors and test connectivity to the Dispel environment (note: IP address will be
471 account specific):

472 **#> tail -f /home/ubuntu/wicket/wicket.log**

473 2.1.3 Configuration

474 With the Wicket ESI connected to the lab environment, the solution may be configured by establishing
475 an account and configuring the cloud infrastructure, configuring the corporate router/firewall to allow
476 authorized connections to and from the Wicket ESI, and configuring the VDI environment to support the
477 remote access to the ICS environments.

478 For full documentation and configuration instructions, see the Dispel documentation at
479 <https://intercom.help/dispel/en/>.

480 Dispel created an organization named “NCCOE” with an Enclave name “NCCoE-Manufacturing” in their
481 pre-production staging environment. A single “user” account was created for accessing the cloud
482 infrastructure environment named nccoe-m-user@dispel.io. Organizations will need to plan for
483 implementing multiple accounts for supporting the “owner” and “admin” roles in addition to the “user”
484 roles. The “owner” and “admin” roles are for monitoring and managing the cloud infrastructure and are
485 separate from the user accounts used to login to the VDI environment.

486 The staging environment was configured without the Dispel multifactor authentication (MFA) settings
487 because personal identity verification (PIV) cards were not available as a supported mechanism, and the
488 lab environment did not support authenticator application or security keys. However, MFA is very
489 important for implementation and is strongly encouraged when planning the implementation. For this
490 effort, to reduce the risk of not having the MFA implementation, NCCoE worked with Dispel to limit
491 access to the cloud infrastructure and the VDI instances to only approved source IP addresses. *The
492 additional protection of restricting access to the cloud infrastructure and VDI instances is also
493 encouraged to reduce the risks associated with the internet-accessible web and RDP services.*

494 **Configure Firewall Settings:**

495 The Wicket ESI needs access to the internet and to the internal OT environment. Table 2-2 below
496 describes the firewall rules implemented on the corporate router/firewall for communications on the
497 internet-facing firewall and internal network zone firewall.

498 Table 2-2 Firewall Rules for Dispel

Rule Type	Source	Destination	Protocol:Port(s)	Purpose
Allow	10.100.1.60	IdAM: 159.65.111.193 Entry Node: 52.162.177.202	TCP/UDP:1194, HTTPS	Outbound Secure Web to Dispel Environment on the Internet
Allow	10.100.1.61	10.100.1.0/24	ICMP TCP/UDP:RDP, SSH, HTTP/HTTPS, SMB, NTP	PLC Controller Scans
Allow	10.100.1.61	Security Onion 10.100.0.26	TCP:1515 UDP:1514	Build 2: Communication between Wazuh Agent and the server
Allow	10.100.1.61	172.16.0.0/22	TCP:RDP, HTTP/HTTPS	Build 2: Authorized Inbound Communications to PCS Environment
Allow	10.100.1.61	Carbon Black 10.100.0.52	TCP:41002	Build 4: Communication port used between Carbon Black Agent and the server
Allow	10.100.1.61	CRS NAT 10.100.0.20	TCP:48898 UDP:48899	Build 4: Inbound Automation Device Specification (ADS) Protocol for Communication with PLC Device

499 Notes:

- 500 ▪ Dispel’s recommended rule for allowing secure shell (SSH) for installation and remote support
501 from the Dispel environment was not enabled for this effort.
- 502 ▪ The rules implemented included restricting these outbound ports to Enclave specific IP
503 addresses.
- 504 ▪ The Enclave’s MTD characteristics were disabled to keep the Enclave’s IP addresses static for the
505 duration of the project.

506 **Configure Virtual Desktop Infrastructure (VDI):**

507 The VDI instance is a fully functional workstation/server within the cloud environment. From the
508 VDI instance, authorized users establish a VPN tunnel to the Wicket ESI within the OT
509 environment and then have the access to the environment configured by the device and firewall
510 configurations. In this effort, NCCoE implanted the VDI configuration to support Build 2 and
511 Build 4. The configuration supports the OT environment’s jump server configuration (allowing
512 RDP and SSH access to systems within the PCS and CRS environment) and remote engineering
513 workstation (configuring the VDI with the tools needed to support the ICS environment). The
514 configuration for each build is detailed in the following sections.

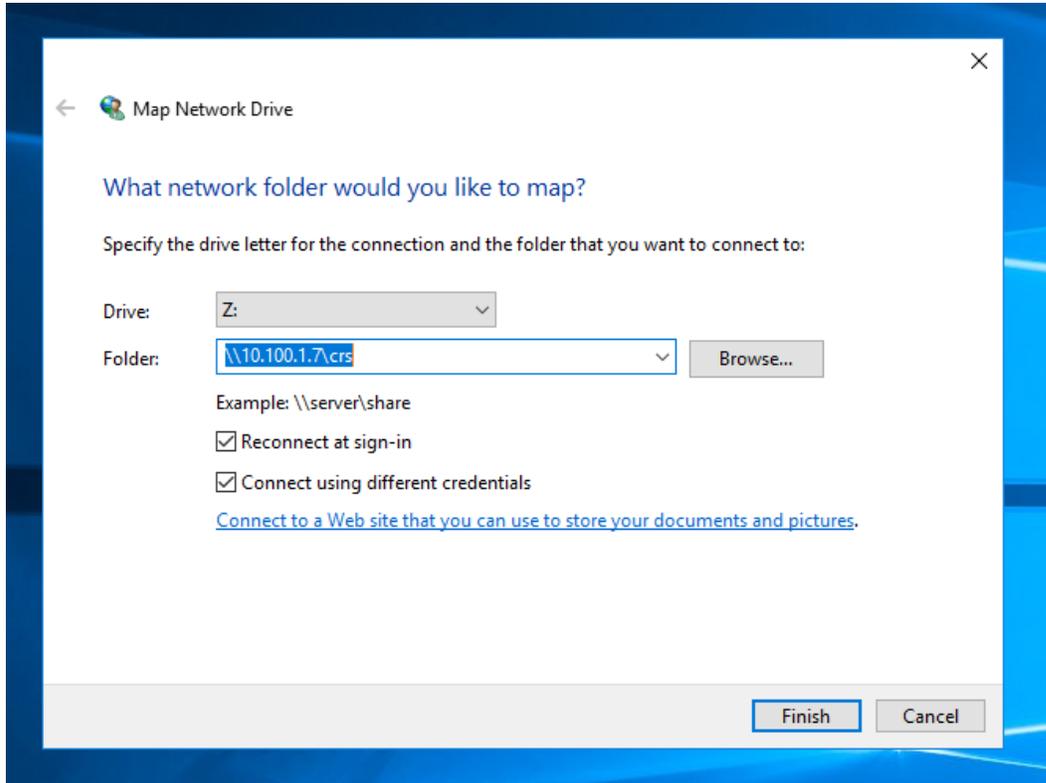
- 515 1. Build 2: PCS Configuration
- 516 i. For the PCS setup, the Dispel VDI was used in a jump server configuration. No
- 517 additional software was installed. The firewall and Wicket ESI configuration
- 518 allowed RDP and SSH connections to the PCS ICS environment. Additionally, RDP,
- 519 SSH, and HTTP/HTTPS access to the Cybersecurity LAN environment was
- 520 authorized for the remote sessions as defined in the previously described firewall
- 521 settings, Table 2-2.
- 522 2. Build 4: CRS Configuration
- 523 i. For the CRS setup, the Dispel VDI was configured as a remote engineering
- 524 workstation. To support the Beckhoff PLC, the TwinCAT 3 XAE software was
- 525 installed on a VDI, and the network drive provided by the GreenTec-USA solution
- 526 and hosted in the DMZ environment that contained the PLC code was mapped to
- 527 the VDI. Additionally, RDP, SSH, and HTTP/HTTPS access to the Cybersecurity LAN
- 528 environment was authorized for the remote sessions as defined in the previously
- 529 described firewall settings, Table 2-2.
- 530 ii. For the interaction with the Beckhoff PLC, the TwinCAT 3 XAE software (TC31-
- 531 FULL-Setup.3.1.4024.10.exe) was installed on the VDI.
- 532 iii. The Dispel VPN connection does not allow split-tunneling so, once the VPN
- 533 connection is established from the VDI to the Wicket ESI, the VDI is disconnected
- 534 from the internet. Therefore, download and installation of software occurred
- 535 prior to connecting to the Wicket ESI.
- 536 iv. Due to the NAT configuration of the RUGGEDCOM RX1510 router between the
- 537 Cybersecurity LAN and the CRS environment, port forwarding rules were
- 538 configured to allow external traffic to reach the Beckhoff CX9020 PLC.
- 539 v. The following rules (Table 2-3) were created in the RX1510 firewall to enable
- 540 destination network address translation (DNAT) from the firewall WAN interface
- 541 (10.100.0.20) to the CRS PLC (192.168.0.30)

542 **Table 2-3 Firewall Rules**

Rule Type	Source	Destination	Destination Port(s)	Purpose
DNAT	10.100.1.61	192.168.0.30	UDP:48899	DNAT (10.100.0.20) - Beckhoff ADS discovery protocol used by the TwinCAT 3 software to discover ADS devices.
DNAT	10.100.1.61	192.168.0.30	TCP:48898	DNAT (10.100.0.20) - Beckhoff ADS protocol used by the TwinCAT 3 software to communicate with the PLC.

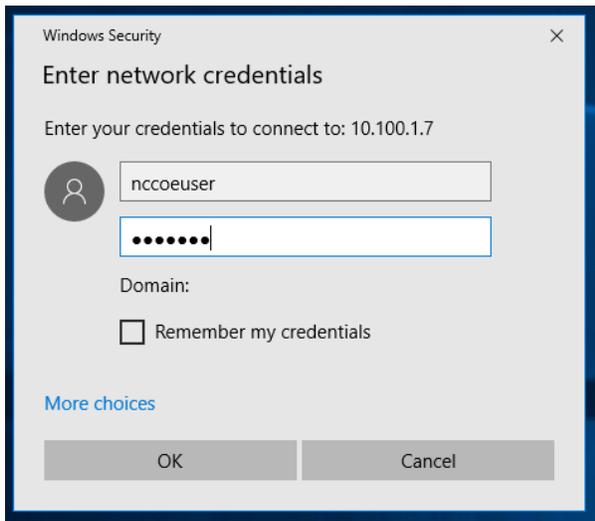
- 543 3. As described in 2.i above, the GreenTec WORMdisk (\\10.100.1.7\crs) was mapped to the
544 VDI to access the PLC code. The configuration to map Windows is shown in Figure 2-2
545 below:

546 **Figure 2-2 Mapping a Network Drive**



- 547 4. After clicking **Finish**, the user is prompted for credentials, as shown in Figure 2-3. An account
548 authorized to access the network drive must be used. This is separate from the Dispel VDI
549 credentials.

550 **Figure 2-3 Authentication to File Server**



551 **2.2 Dragos**

552 The Dragos platform implementation in Build 3 consists of two physical servers hosting the Dragos
 553 SiteStore and the Dragos sensor to meet the behavioral anomaly detection (BAD), hardware
 554 modification, firmware modification, and software modification capabilities. Dragos utilizes a
 555 combination of a passive sensor and integration with the OSISOFT PI Server to monitor critical networks
 556 for anomalies. OSISOFT PI performs active querying to retrieve information about endpoints in the CRS
 557 environment, which is shared with Dragos.

558 **2.2.1 Host and Network Configuration**

559 Dragos is installed and configured to support the CRS Environment in Build 3. The overall build
 560 architecture is shown in [Figure B-3](#), and the Dragos specific components are listed in Table 2-4.

561 **Table 2-4 Dragos Deployment**

Name	System	OS	CPU	Memory	Storage	Network
VMware Server	Dell OEMR R740	VMware 6.7.0 Update 3	2x Intel 6130 CPU	384 GB	2x 1.5TB Mirror 6x 8TB RAID 10	Testbed LAN 10.100.0.62/24
Dragos Server	VMware	CentOS 7	48x vCPU	192 GB	215 GB 10 GB 1.5 TB 1.5 TB	Testbed LAN 10.100.0.63/24
Dragos Sensor	Dell OEM	CentOS 7	64x vCPU	128 GB	240 GB 1 TB	Testbed LAN 10.100.0.64/24

562 2.2.2 Installation

563 The Dragos platform, which includes the SiteStore server and the Dragos sensor, was delivered as pre-
564 configured hardware appliance by Dragos with the required IP addresses already assigned. The only
565 installation step was correctly connecting the server and the sensor management ports to the Testbed
566 LAN and adding the switch port analyzer (SPAN) port connection to the sensor.

567 The Dragos Platform Administrator Guide and Dragos Platform User Guide for Release 1.7 were used to
568 guide the installation. Customers can obtain these guides from Dragos.

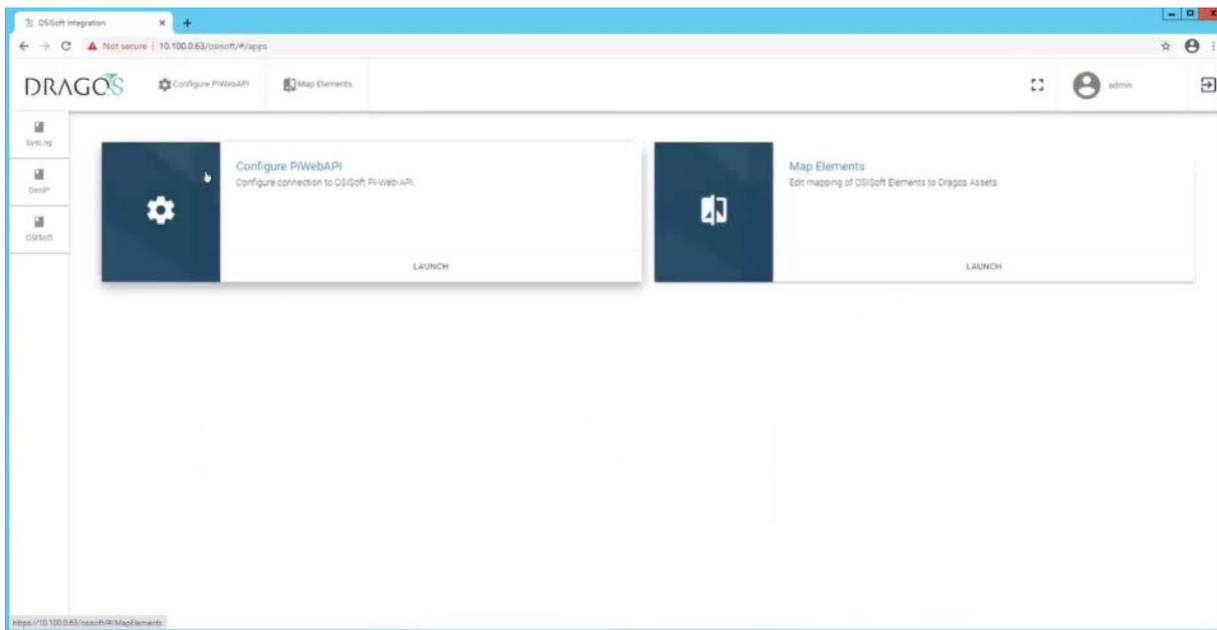
569 2.2.3 Configuration

570 In addition to the standard configuration preset by Dragos, the Dragos Platform was configured to work
571 with OSIssoft PI for alerting on certain conditions.

572 Configure the Dragos SiteStore Server:

- 573 1. Configure the data connection between Dragos SiteStore and OSIssoft PI Server:
 - 574 a. Once installation is successful, open a browser to access the configuration screen by us-
575 ing the URL **https://<SiteStore ip address>/osisoft/#/apps**. (Figure 2-4)

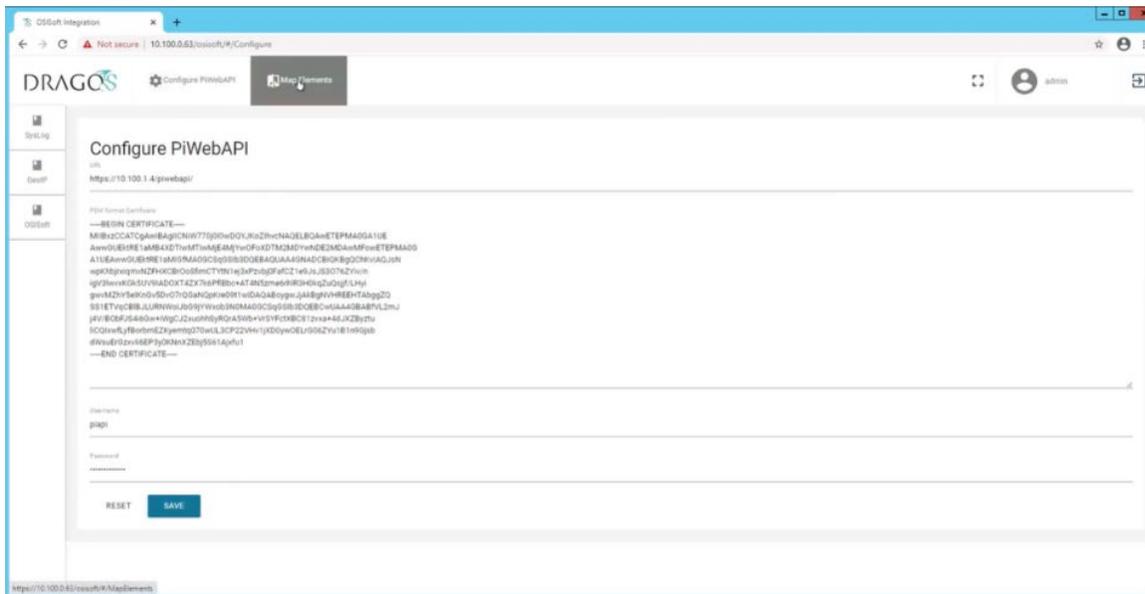
576 **Figure 2-4 Dragos OSIssoft PI Server Integration**



- 577 b. Click **Configuration Pi Web API** to open a screen for filling out the required information,
578 including privacy enhanced mail (PEM) format certificate and password for secure
579 authentication (Figure 2-5).
 - 580 i. Upload the server public key for the HTTPS certificate.
 - 581 ii. Specify the user credentials for the OSIssoft PI Web API interface.

582 iii. Click **Save**.

583 Figure 2-5 Dragos PI Web API Configuration



584
585 c. Click **Map Elements** to access the interface to pair elements between OSIsoft PI Server
586 and the Dragos Platform assets. Here, the PLC in **OSIsoft Elements** panel is paired with
587 Beckhoff asset in the Dragos Platform asset (Figure 2-6).

588 i. Select the OSIsoft Database **CRS-backup** on the left side to access the devices list
589 from the Historian Database.

590 ii. Select the **Default NetworkID RFC 1918** and use the Filer options to find specific
591 assets.

592 iii. For each asset in the OSIsoft Database, select the corresponding asset in the Dra-
593 gos asset repository and click **Pair Selected**.

594 iv. Repeat this process for each asset until all paired assets are listed in the **Paired**
595 **Data** table (Figure 2-7).

596 1) PLC paired to 192.168.0.30

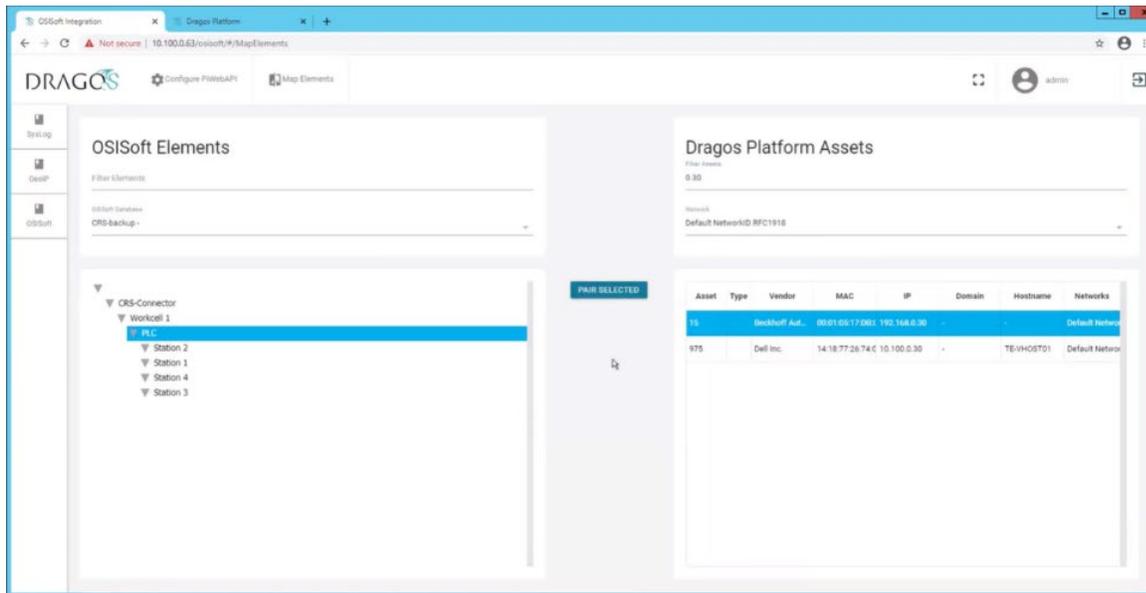
597 2) Station 1 paired to 192.168.1.101

598 3) Station 2 paired to 192.168.1.102

599 4) Station 3 paired to 192.168.1.103

600 5) Station 4 paired to 192.168.1.104

601 **Figure 2-6 OSISOFT PI Server to Dragos Asset and Data Pairing**



602

603 **Figure 2-7 OSISOFT PI Server and Dragos Paired Data Elements**

Paired Data

Delete	Asset	OSISOFT Name	Type	Vendor	MAC	IP	Domain
<input type="checkbox"/>	15	PLC		Beckhoff Automation GmbH	-	192.168.0.30	-
<input type="checkbox"/>	3176	Station 2			B0:D5:CC:FE:6E:81	(2) 192.168.1.102, FE80:B2D5:CCFF:FEFE:6EB1	(2) machining-station-2_local,_top.local
<input type="checkbox"/>	3186	Station 1			B0:D5:CC:FA:70:C9	(2) 192.168.1.101, FE80:B2D5:CCFF:FEFA:70C9	(2) machining-station-1_local,_top.local
<input type="checkbox"/>	3180	Station 3			B0:D5:CC:FA:7A:43	(2) 192.168.1.103, FE80:B2D5:CCFF:FEFA:7A43	(2) machining-station-3_local,_top.local
<input type="checkbox"/>	3177	Station 4			B0:D5:CC:F4:26:EC	(2) 192.168.1.104, FE80:B2D5:CCFF:FEF4:26EC	(2) _top.local, machining-station-4.local

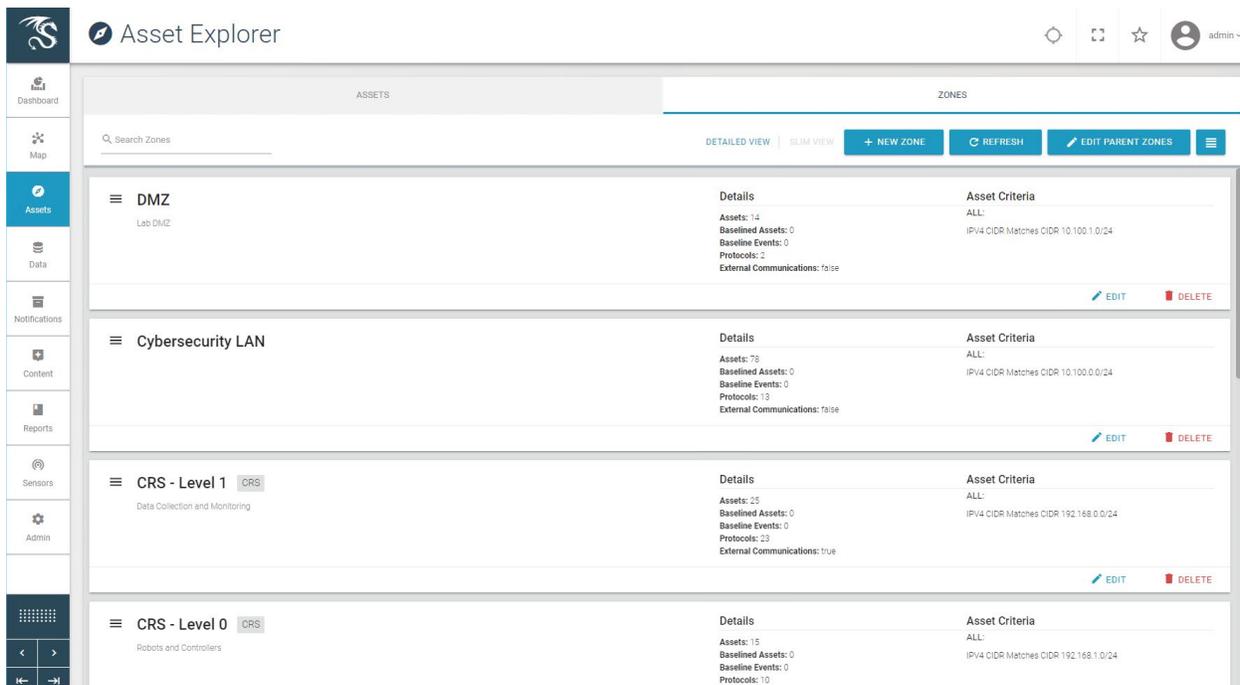
604

605 a. **Configure Zones**

606 **NOTE:** Zones are ordered in a similar manner to firewall rules. In other words, higher rules
 607 have priority over lower rules.

608 i. Click **Assets** and select the **Zones** tab (Figure 2-8).

609 Figure 2-8 Dragos Zone Administration Page



- 610 b. Click **+ New Zone** (Figure 2-9) and define the following zones:
- 611 i. Name: **DMZ**:
- 612 1) Description: Lab DMZ
 - 613 2) Zone Criteria (Match ALL):
 - 614 a) IPV4 CIDR Matches CIDR 10.100.1.0/24
- 615 ii. Name: Testbed LAN:
- 616 1) Description: Lab Testbed LAN
 - 617 2) Auto Zone Criteria (Match ALL):
 - 618 a) IPV4 CIDR Matches CIDR 10.100.0.0/24
- 619 iii. Name: CRS:
- 620 1) Description: **Parent CRS**
 - 621 2) No Criteria
- 622 iv. Name: CRS – Level 0:
- 623 1) Description: Robots and Controllers
 - 624 2) Parent Zone: **CRS**
 - 625 3) Auto Zone Criteria (Match **ALL**):
 - 626 a) IPV4 CIDR Matches CIDR 192.168.1.0/24

- 627 v. Name: CRS – Level 1:
- 628 1) Description: **Lab DMZ**
- 629 2) Parent Zone: **CRS**
- 630 3) Auto Zone Criteria (Match **ALL**):
- 631 a) IPV4 CIDR Matches CIDR 192.168.0.0/24

632 **Figure 2-9 Dragos Create Zone Pop-up**

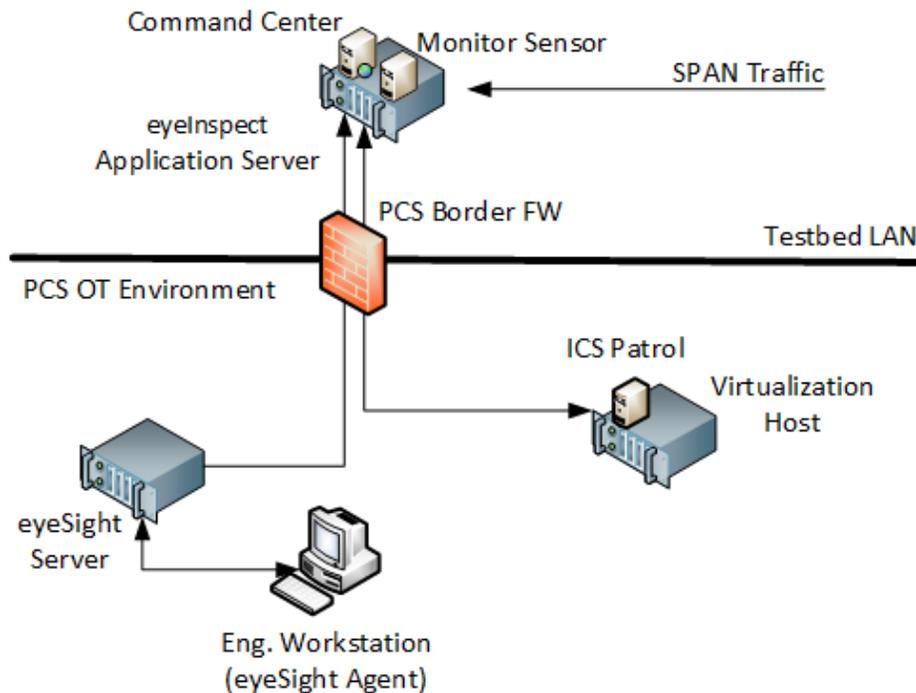
The screenshot shows a 'Create Zone' pop-up window. At the top, the title is 'Create Zone'. Below the title, there are three input fields: 'Name' with the value 'DMZ', 'Description' with the value 'Lab DMZ', and 'Parent Zone' with a search prompt 'Search for an existing Parent Zone, or create a new Parent Zone'. Below these fields is a section titled 'Auto Zoning Criteria'. It contains two sections: 'Results must match ALL of the following:' and 'Results must match ANY of the following:'. The 'ALL' section contains a table with one row: 'IPV4 CIDR' (selected from a dropdown), 'Matches CIDR.' (selected from a dropdown), and '10.100.1.0/24' (the value). Below the table is a '+ ADD ATTRIBUTE' button. The 'ANY' section is currently empty and also has a '+ ADD ATTRIBUTE' button. At the bottom right of the pop-up are 'CANCEL' and 'SAVE' buttons.

633 2.3 Forescout Platform

634 The Forescout products included in the practice guide are eyeInspect (formally SilentDefense), eyeSight,
635 ICS Patrol, and Forescout Console. These products are utilized in Build 2 to meet the BAD, hardware
636 modification, firmware modification, and software modification capabilities. The Forescout

637 implementation utilizes different components and modules installed on different devices to monitor
 638 critical networks for anomalies and active query capabilities to retrieve information about endpoints in
 639 the PCS environment. A high-level of the key server and agent components is presented in Figure 2-10.

640 **Figure 2-10 Forescout High-Level Components and Dataflows**



641 **eyeInspect (formally SilentDefense)**

642 The eyeInspect (Version 4.1.2) control server and monitoring sensor are installed on a single appliance
 643 with a management interface on the Testbed VLAN and network monitoring capabilities through a
 644 dedicated SPAN port. The SPAN port provides passive monitoring for network-based anomalies and
 645 retrieves information about endpoints within the network. The eyeInspect appliance also serves as the
 646 command center for supporting the ICS Patrol and eyeSight components.

647 **eyeSight**

648 Forescout eyeSight (Version 8.2.1) provides enhanced network monitoring and response using an agent
 649 installed on endpoints. In this build, eyeSight instances are configured through the Forescout Console to
 650 provide additional monitoring and reporting information to eyeInspect.

651 **ICS Patrol**

652 Forescout ICS Patrol (Version 1.1.2-4.a826b94) is a sensor that supports active queries for ICS devices to
 653 obtain status and other information such as hardware configuration and firmware version. ICS Patrol
 654 queries and reporting results are managed through eyeInspect.

655 **Forescout Console**

656 The Forescout Console (Version 8.2.1) is a Java-based application for configuring and managing eyeSight
 657 and eyeSight agents. The Forescout Console is installed on a computer with network access to the
 658 eyeSight server.

659 2.3.1 Host and Network Configuration

660 Forescout was installed and configured to support the PCS Environment as part of Build 2. The overall
 661 build architecture is provided in [Figure B-2](#) with the Forescout specific components in Table 2-5 and the
 662 eyeSight agents in Table 2-6.

663 **Table 2-5 Forescout Deployment**

Name	System	OS	CPU	Memory	Storage	Network
eyeInspect control server	Dell Embedded Box PC 5000	Ubuntu 16.04	Intel i7-6820EQ	32 GB	250 GB	Testbed LAN 10.100.0.65
Forescout Console	Hyper-V VM	Windows 2012R2	2x vCPU	6 GB	65 GB	Testbed LAN 10.100.0.25
eyeSight Server	Dell R640	Ubuntu 16.04.06	Intel Xeon Silver 4110	32	600 GB	PCS VLAN 2 172.16.2.61
ICS Patrol	VirtualBox VM	Ubuntu 16.04.06	2x vCPU	2 GB	40 GB	PCS VLAN 2 172.16.2.62

664 For the lab environment, network connectivity between the components in the Testbed LAN and the
 665 components in the PCS environment required the following persistent route configured on Testbed LAN
 666 systems:

```
667 route -p ADD 172.16.0.0 MASK 255.255.252.0 10.100.0.40
```

668 The following systems were configured to utilize the eyeSight Agents.

669 **Table 2-6 eyeSight Agent Deployment**

Name	System	OS	CPU	Memory	Storage	Network
Engineering Workstation	Dell T5610	Windows 7	Intel i5-4570	16 GB	465 GB	PCS VLAN 3 172.16.3.10
HMI Host	Generic	Windows 7	Intel i5-4590	8 GB	233 GB	PCS VLAN 1 172.16.1.4

670 Additional details for Build 2 are available in Section 4.5 of Volume B.

671 2.3.2 Installation

672 The Forescout products included in the practice guide are eyeInspect, Forescout Console, ICS Patrol, and
 673 eyeSight. These products are installed as indicated in the appropriate subsection below. To support
 674 these components, the PCS Gateway/Firewall rules were updated as follows (Table 2-7).

675 **Table 2-7 Firewall Rules for Forescout**

Rule Type	Source	Destination	Port(s)	Purpose
Allow	10.100.0.65	172.16.2.61	22 (ssh) 9999 9092	System Management eyeInspect Data eyeInspect Data
Allow	10.100.0.65	172.16.2.62	22 (ssh) 9001	System Management eyeInspect Data

676 2.3.2.1 eyeInspect

677 eyeInspect is an appliance hosted on a Dell Embedded Box PC 5000. The unit was placed within a
 678 standard datacenter rack unit with the eyeSight appliance and connected to the network as described in
 679 Section 2.3.1. SPAN ports from the DMZ, Testbed LAN, and PCS VLAN 1, 2, and 3 switches were routed
 680 to the appliance for passive network monitoring. Installation also required uploading the license file
 681 after successfully logging onto the appliance.

682 2.3.2.2 Forescout Console

683 Forescout Console was installed following the standard installation procedures. Instructions can be
 684 found in the Forescout Installation Guide Version 8.2.1 available at <https://docs.forescout.com>. The
 685 software is available from <https://forescout.force.com/support/s/downloads>, where current and past
 686 versions are available. Login credentials were provided by Forescout.

687 2.3.2.3 eyeSight

688 Forescout eyeSight is an appliance hosted on a 1U Dell R640 that is installed within a standard
 689 datacenter rack and connected to the network as described in the previous section.

690 2.3.2.4 eyeSight SecureConnector Agent

- 691 1. In a browser on a system with web connectivity to the eyeSight server, navigate to
 692 <https://172.16.2.61/sc.jsp> to access the SecureConnector download page (Figure 2-11) and
 693 follow these steps:
 - 694 a. Select Create SecureConnector for: **Windows**.
 - 695 b. Enable **Show the SecureConnector icon on the endpoint systray**.
 - 696 c. Select **Install Permanent As Service**.
 - 697 d. Click **Submit**.

- 698 2. Download the Forescout Agent (Figure 2-12):
- 699 a. Select Version **Win64**.
- 700 b. Click **Download**.
- 701 3. Install the downloaded agent on the target systems using an administrator account.

702 **Figure 2-11 Forescout SecureConnector Distribution Tool**

703 **Figure 2-12 Forescout Agent Download**

704 **2.3.2.5 ICS Patrol**

705 Forescout ICS Patrol (Version 1.1.2-4.a826b94) is a sensor that is deployed on an existing VirtualBox host
 706 in the PCS environment. Ubuntu 16.04.06 is required for proper installation and can be downloaded
 707 from <http://old-releases.ubuntu.com/releases/xenial/ubuntu-16.04.6-server-amd64.iso>. Install the
 708 operating system on a VM connected to PCS VLAN 2 following the procedures from the Silent Defense
 709 Installation and Configuration Guide 4.1.2 document Section 2.2.2, Installing the Linux Ubuntu OS.

- 710 1. Install the ICS Patrol Component from the Silent Defense Installation and Configuration Guide
 711 4.1.2 document Sections 2.2.4 and 2.2.5 following these steps:
- 712 a. Establish an SSH session to the eyeInspect appliance.

713 b. Copy the components to the ICS Patrol VM:

```
714 $ scp os_provisioning_4.1.1_install.run \
715 main_configuration_4.1.1_install.run \
716 silentdefense@172.16.2.62:/home/silentdefense
```

717 c. SSH to the ICS Patrol VM and execute the installation components:

```
718 $ chmod a+x *.run
719 $ sudo ./os_provisioning_4.1.1_install.run
720 $ sudo ./main_configuration_4.1.1_install.run
721 $ sudo reboot
```

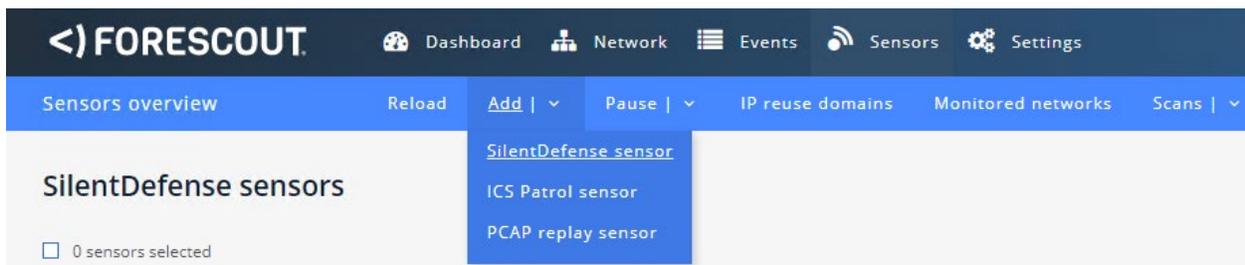
722 2.3.3 Configuration

723 The eyeSight agents and ICS Patrol do not require specific configurations.

724 2.3.3.1 eyeInspect

- 725 1. Access the eyeInspect web interface and log in with an administrator account.
- 726 2. Register the local sensor for SPAN traffic monitoring:
 - 727 a. Click the **Sensors** option to access the Sensor Admin/Overview Page (Figure 2-13).
 - 728 b. Click the menu option **Add > SilentDefense sensor**.
 - 729 c. Specify the sensor parameters in the dialog box (Figure 2-14).

730 Figure 2-13 eyeInspect Sensor Admin/Overview Page – Add Sensor



731 Figure 2-14 Adding a New SilentDefense Sensor Dialog

Add a new sensor

Policy ★ Import sensor configuration ▼

Sensor name ★ sensor-bundle-nccoe

Sensor Address ★ localhost

Port ★ 9999

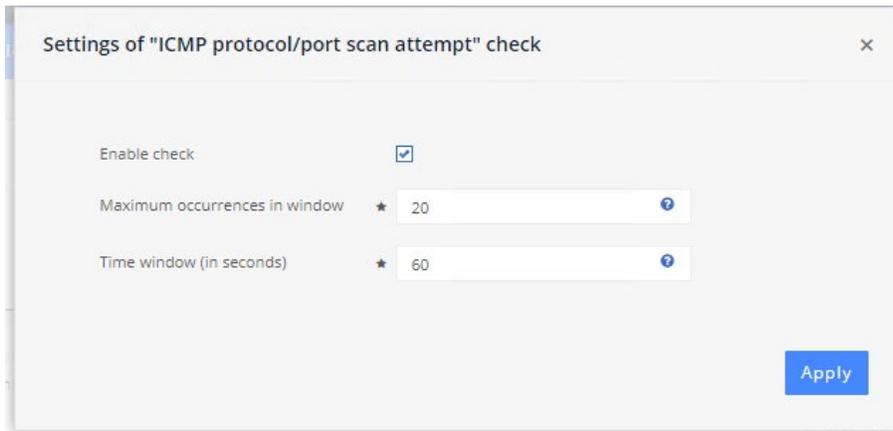
IP address reuse Yes No

Associate monitored networks Yes No

Create default LAN CP profiles Yes No

Finish

- 732 3. Adjust Passive Monitoring settings:
- 733 a. From the Dashboard, click **Sensors**.
- 734 b. Select the **SilentDefense Sensor** from the list of available sensors.
- 735 c. Click the **Industrial Threat Library Overview** option in the upper right corner.
- 736 d. Click the **Security** menu option on the left under **Checks by Category**.
- 737 e. Enter "ICMP" in the Search field to reduce the list of available options.
- 738 f. Click the **ICMP** protocol/port scan attempt to open the settings dialog box (Figure 2-15)
- 739 and verify the following settings:
- 740 i. Verify **Enable Check** is selected.
- 741 ii. Verify **Maximum occurrences in window** is set to **20**.
- 742 iii. Verify **Time Window (in seconds)** is set to **60**.

743 **Figure 2-15** eyelnspect ICMP Protocol/Port Scan Attempt Settings744 g. Select **Portscan Detection** under Built-in Modules (Figure 2-16).745 **Figure 2-16** eyelnspect Sensor Configuration Options

Sensor attributes

Sensor name: sensor-bundle-nccoe
 State: ✔ Connected
 Address: localhost
 Port: 9999
 IP reuse domains
 Monitored networks

Built-in modules

0 modules selected

Name	State
<input type="checkbox"/> Portscan detection	✔ Detecting
<input type="checkbox"/> Man-in-the-middle detection	✔ Detecting
<input type="checkbox"/> Malformed packet detection	✔ Detecting
<input type="checkbox"/> Frequent event aggregation	✔ Active
<input type="checkbox"/> Visual analytics	✔ Active
<input type="checkbox"/> Event logging	✔ Active

Network whitelists

Communication patterns (LAN CP)

0 profiles selected

ID	Name	State
<input type="checkbox"/> 8	TCP communications	✔ Detecting
<input type="checkbox"/> 9	UDP communications	✔ Detecting

2 profiles

Protocol fields (DPBI)

0 profiles selected

No profiles available.

0 profiles

Network intelligence framework

Industrial threat library (ITL)

0 library selected

Name	State
<input type="checkbox"/> Industrial threat library checks	✔ Active

Custom checks (SD Scripts)

0 scripts selected

ID	Name	State
<input type="checkbox"/> 10	cve_2019_0708_monitor	✔ Active
<input type="checkbox"/> 11	CVE_2020_0796_monitor.v1.0	✔ Active
<input type="checkbox"/> 12	CVE-2020-1350 Monitor v1.0	✔ Active
<input type="checkbox"/> 13	ETHIP/CSP - PCCC Monitor v0.6	✔ Active
<input type="checkbox"/> 14	Host and Link Add-Ons v1.28	✔ Active
<input type="checkbox"/> 15	HTTP HLI v1.4	✔ Active
<input type="checkbox"/> 17	MAC white listing v1.1	✔ Active
<input type="checkbox"/> 18	MODBUSTCP Monitor v0.8	✔ Active
<input type="checkbox"/> 19	MS17_010 Monitor v1.1	✔ Active
<input type="checkbox"/> 20	Profinet Monitor v0.3.1	✔ Active
<input type="checkbox"/> 22	Ripple20 Monitor v1.0	✔ Active
<input type="checkbox"/> 23	Suppress alerts on known-good IPs v1.0	✔ Active
<input type="checkbox"/> 24	Vnet/IP Monitor v0.3	✔ Active
<input type="checkbox"/> 25	Host and Link Add-Ons v1.30	✔ Active

14 scripts

746

747 h. Click the **Settings** tab and set the following parameters (Figure 2-17):

748

i. **Sensitivity level:** User defined

749

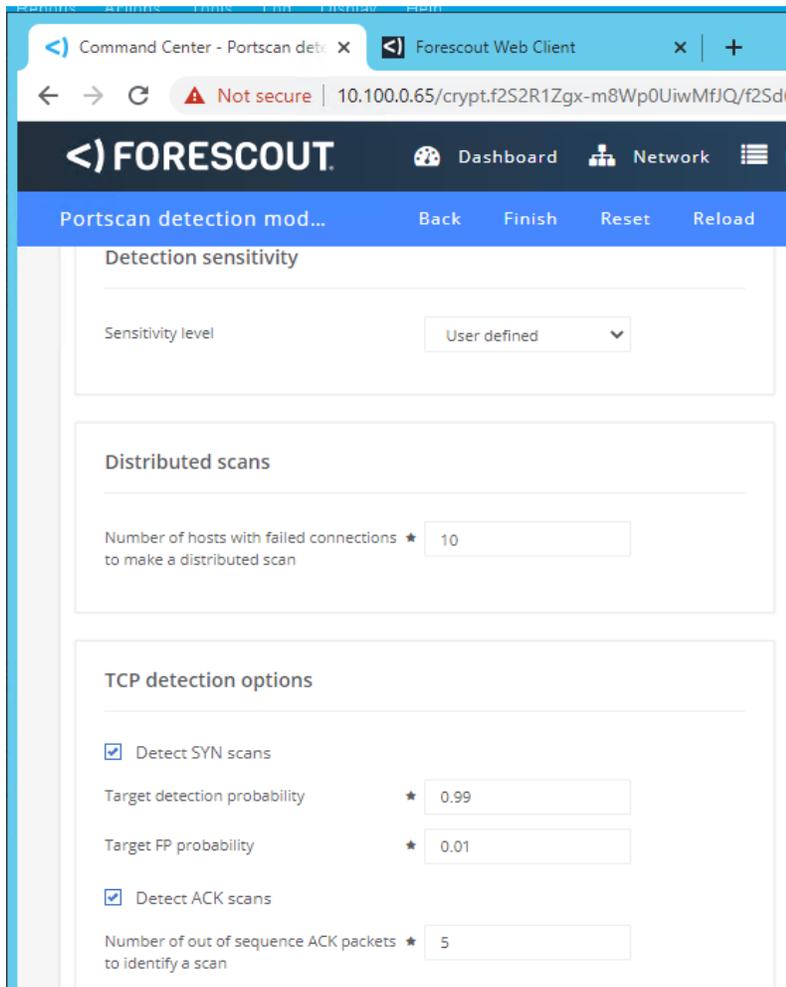
ii. **Number of Hosts with failed connections to make a distributed scan:** 10

750

iii. **Detect SYN scans:** Checked

- 751 iv. **Target detection probability:** 0.99
- 752 v. **Target FP probability:** 0.01
- 753 vi. **Detect ACK scans:** Checked
- 754 vii. **Number of out of sequence ACK packets:** 5

755 **Figure 2-17** eyespect Portscan Detection Settings



- 756
- 757 4. Register the ICS Patrol Sensor:
- 758 a. From the Sensor admin page, click the menu option **Add > ICS Patrol sensor**.
- 759 b. Specify the sensor parameters in the dialog box (Figure 2-18).

760 **Figure 2-18 Add ICS Patrol Sensor Dialog**

Add a new sensor [X]

Sensor name * PCS_Sensor

Sensor Address * 172.16.2.62

Port * 9001

IP address reuse Yes No

Associate monitored networks Yes No

Monitored networks *
Lab LAN (10.100.0.0/24)
Collaborative Robotics System (192.168.0.0/23)
Process Control System VLAN1 (172.16.1.0/24)
Process Control System VLAN2 (172.16.2.0/24)
Process Control System Engineering (172.16.3.0/24)
Process Control System PLC Data Traffic (172.16.4.0/24)
Use CTRL+Click to select multiple options.

Targetable networks *
172.16.1.0/24
172.16.2.0/24
172.16.3.0/24
172.16.4.0/24
192.168.0.0/23
10.100.2.0/24
10.100.1.0/24
Use CTRL+Click to select multiple options.

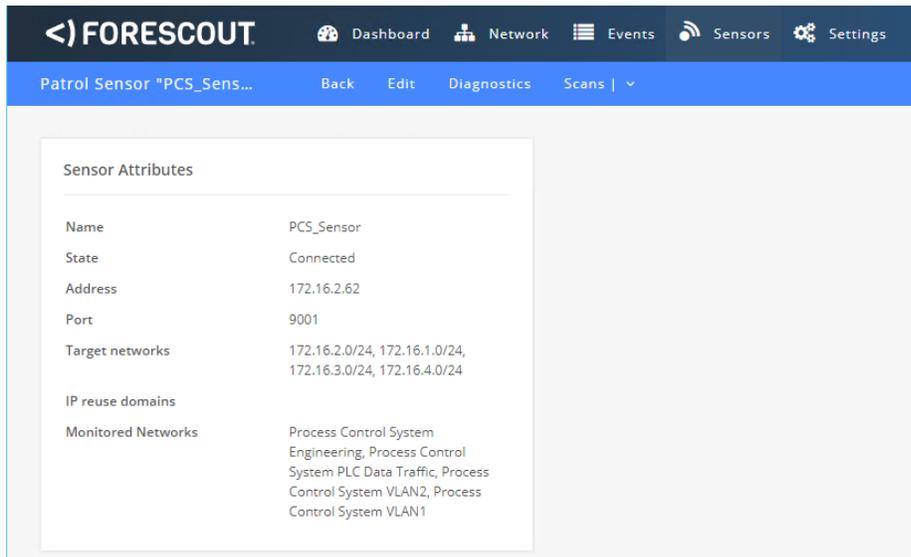
Target username * silentdefense

Target password *

Finish

- 761 c. Define a scan policy to periodically check the PCS PLC to monitor for changes.
- 762 i. Click the PCS Sensor created in the previous step to open the sensor admin page
- 763 (Figure 2-19).

764 Figure 2-19 ICS Patrol Sensor Admin Page



- 765 ii. Click the menu option **Scans > Scan Policies**.
- 766 iii. In the dialog option (Figure 2-20) enter the scanning parameters:
- 767 1) **Name:** PCS PLC
- 768 2) **Scan Type:** EtherNet/IP
- 769 3) **Target Type:** Custom target
- 770 4) **IP address reuse:** No
- 771 5) **Network Address:** 172.16.2.102
- 772 6) **Schedule:** Yes
- 773 7) **Frequency:** Repeat
- 774 8) **Interval:** 1 . Select "Hours" from the drop-down menu.
- 775 9) Click **Finish**.

776 **Figure 2-20 Add an ICS Patrol Scan Policy**

Add scan policy

Name: ★ PCS PLC

Description: [Empty text area]

Scan type: ★ Active IPs OS/Ports Custom Windows OT Ports Siemens S7 EtherNet/IP

Target type: ★ Custom target

IP address reuse: Yes No

Network addresses: ★ 172.16.2.102

Schedule: Yes No

Frequency: ★ Repeat

Start date: ★ Jun 3, 2021 12:00:00

Interval: ★ 1 Hours

Finish

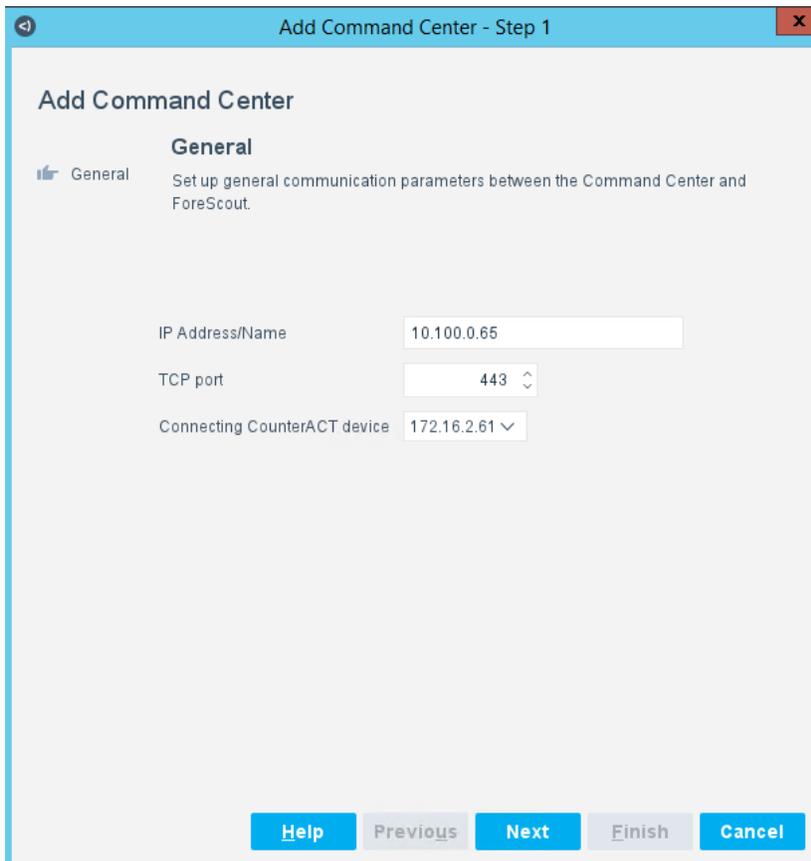
777 **2.3.3.2 eyeSight**

778 Using the Forescout Console application, users may configure, monitor, and manage the eyeSight
 779 appliance and agents. The Forescout Console is also used to test and verify connectivity to the
 780 eyeInspect server.

- 781 1. Login to the Forescout Console.
- 782 2. Select the Gear Icon in the upper right corner or the **Tools > Option** menu item to bring up the
 783 Options display.
- 784 3. Enter "Operational" in the search bar.
- 785 4. Select the **Operational Technology** tab on the left side of the screen to display the current
 786 settings.
- 787 5. Select the IP entry for the Command Center and select **Add** to start the workflow process.

- 788 a. Specify General Information (Figure 2-21):
- 789 i. Enter the Command Center IP Address "10.100.0.65" for IP Address/Name.
- 790 ii. Select "172.16.2.61" from **the Connecting CounterAct device** drop-down menu.
- 791 iii. Select "443" from the TCP Port drop-down menu.

792 **Figure 2-21 eyeSight Add Dialog – General Information**



- 793 b. Click **Next**.
- 794 c. Enter the command center credentials (Figure 2-22).
- 795 d. Click **Finish**.

796 Figure 2-22 eyeSight Add – Command Center Credentials

Add Command Center - Step 2 of 2

Add Command Center

General

Command Center Credentials

Command Center Credentials

Enter access credentials to the Command Center.

Credentials

User name

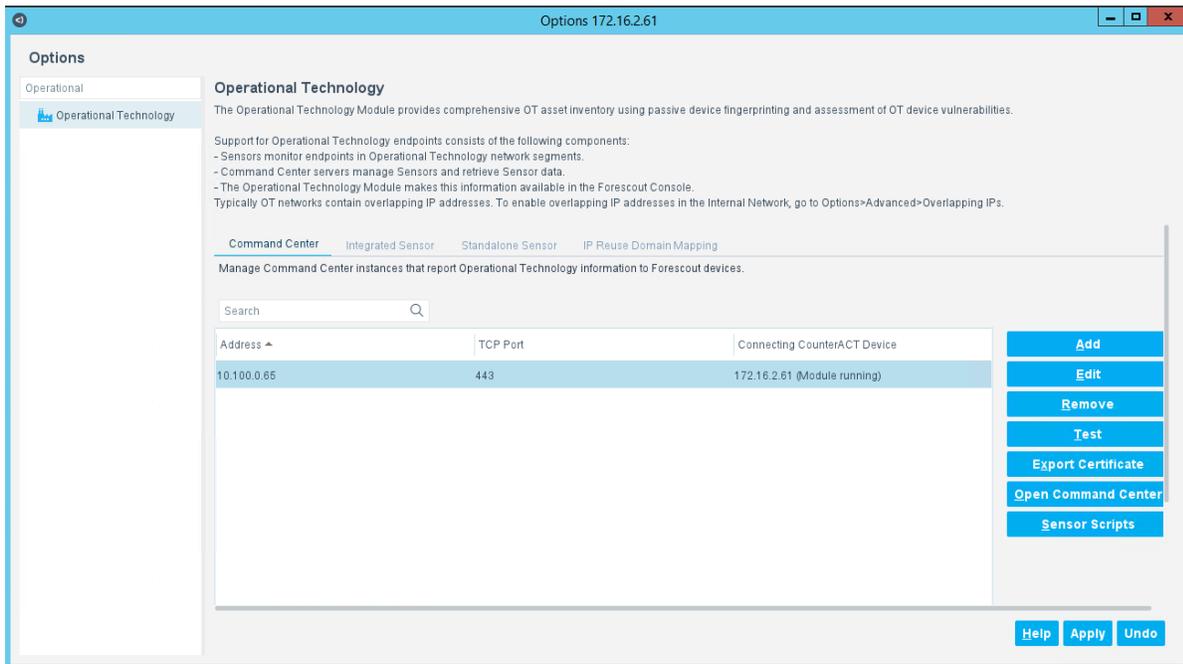
Password

Confirm password

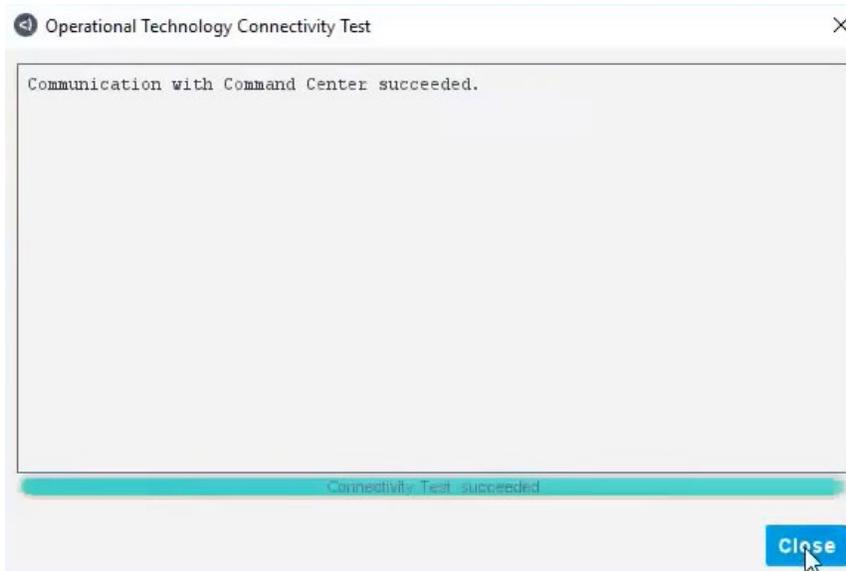
[Help](#) [Previous](#) [Next](#) [Finish](#) [Cancel](#)

- 797 6. Select the IP address for the Command Center and Click **Test** (Figure 2-23). If the connection is
- 798 successful, a message like the one shown in Figure 2-24 is displayed.
- 799 7. Click **Apply** to save the changes.
- 800 8. Click **Close** to close the message.

801 **Figure 2-23 eyeSight OT Settings**



802 **Figure 2-24 eyeSight Test Connection Successful Message**



803 **2.4 GreenTec-USA**

804 The GreenTec-USA products included in this practice guide are the ForceField and WORMdisk zero trust
 805 storage devices. These products were utilized in Builds 1, 2, 3, and 4 to meet the File Integrity Checking
 806 capability by storing and protecting critical PCS and CRS data from modification and deletion.

807 **ForceField**

808 A ForceField hard disk drive (HDD) provides a protected write-once-read-many data storage location for
 809 historian data backups and database backups. Data is immediately protected as it is written to the HDD
 810 in real time, permanently preventing the data from modification and deletion.

811 **WORMdisk**

812 A WORMdisk HDD provides a protected data storage location for PLC logic, device firmware, and
 813 approved software applications for use in the manufacturing environment. Data is protected by
 814 “locking” individual partitions of the HDD using a software utility, permanently preventing the data from
 815 modification and deletion.

816 **2.4.1 Host and Network Configuration**

817 The WORMdisk and ForceField HDDs were installed in a rack-mount server appliance provided by
 818 GreenTec-USA and described in Table 2-8. The overall build architectures utilizing this appliance and
 819 devices are described in Section 4.5 in Volume B.

820 **Table 2-8 GreenTec-USA WORMdrive and ForceField Deployment**

Name	System	OS	CPU	Memory	Storage	Network
GreenTec-USA Server	Supermicro x8 Series Server	Ubuntu 18.04	2x Intel Xeon E5620	16 GB	750 GB OS 1.0 TB WORMdisk 1.0 TB ForceField	DMZ 10.100.1.7

821 **2.4.2 Installation**

822 The ForceField and WORMdisk HDDs were hosted on a hardware appliance provided by GreenTec-USA.
 823 The unit was placed within a standard datacenter rack unit and connected to the network as shown in
 824 [Figure B-1](#), [Figure B-2](#), [Figure B-3](#), and [Figure B-4](#).

825 Full documentation and installation guides are provided to customers by GreenTec-USA.

826 NIST chose to utilize Samba as the network file sharing protocol due to the prevalence of Windows and
 827 Linux workstations within the testbed. The GreenTec-USA appliance did not come with Samba pre-
 828 installed, so installation was performed via the Ubuntu Advanced Packaging Tool and the Ubuntu
 829 package repository.

830 NOTE: GreenTec-USA typically provides turnkey server storage solutions. Installation and configuration
 831 of file sharing packages and other software will likely not be required.

832 NOTE: Many of the commands used to manage the ForceField and WORMdisk HDDs must be executed
 833 by a user with superuser privileges or as the root user.

834 1. Add the default gateway so the appliance can communicate to other devices on the network
 835 using the following command:

836 `$ sudo route add default gw 10.100.1.1`

837 2. In a terminal window on the GreenTec-USA appliance, execute these commands:

```
838 $ sudo apt update
839 $ sudo apt -y install samba
840 $ sudo ufw allow samba
```

841 2.4.3 Configuration

842 The appliance provided by GreenTec-USA for this project was preconfigured with the ForceField HDD as
843 device `/dev/sdc` and the WORMdisk HDD as device `/dev/sdb`.

844 2.4.3.1 ForceField HDD

845 The ForceField HDD is configured as a mounted volume, allowing the drive to be used as a typical HDD
846 by using native operating system commands.

847 1. Create a mount point (empty directory) for the ForceField HDD using the following command:

```
848 $ sudo mkdir /mnt/forcefield
```

849 2. Start the ForceField WFS volume manager to mount the drive using the following command:

```
850 $ sudo /opt/greentec/forcefield/bin/wfs /dev/sdc /mnt/forcefield/
```

851 2.4.3.2 WORMdisk HDD

852 The WORMdisk is divided into 120 partitions to enable periodic updates and revisions to the protected
853 data (i.e., data in the “golden” directory). Once a partition is locked it cannot be modified, so the next
854 sequential partition on the drive is used as the new “golden” directory.

855 1. Format the WORMdisk with 120 partitions (NOTE: this operation must be performed from the
856 command line as administrator on a computer with the Microsoft Windows OS) using the
857 following command:

```
858 > gt_format.exe 1 /parts:120
```

859 2. In the Ubuntu OS, create the mountpoint for the WORMdisk HDD partition using the following
860 command:

```
861 $ sudo mkdir /mnt/golden
```

862 3. Add a persistent mount to the `/etc/fstab` file:

```
863 $ sudo echo "/dev/sdb2 /mnt/golden fuseblk
864 rw,nosuid,nodev,relatime,user_id=0,group_id=0,allow_other,blksize
865 =4096 0 0" >> /etc/fstab
```

866 4. Create a directory structure within the “golden” directory and copy approved files into those
867 directories (e.g., PLC logic, device firmware, approved software).

868 5. Once all files have been copied and verified, lock the partition to protect the data:

```
869 $ sudo /greentec/Ubuntu/wvenf /dev/sdb2
```

870 When it is time to create a new “golden” partition, the partition names in the `/etc/fstab` file must be
 871 updated to point to the correct partition. The following instructions provide an example process to
 872 update the files and increment the golden partition from `/dev/sdb2` to `/dev/sdb3`.

873 1. On the GreenTec-USA appliance, create a temporary directory, mount the folder to the next
 874 unlocked WORMdisk partition, and copy existing “golden” files to the temporary directory:

```
875 $ sudo mkdir /mnt/tmp
876 $ sudo mount /dev/sdb3 /mnt/tmp
877 $ sudo cp -R /mnt/golden /mnt/tmp
```

878 2. Update the files and folders in the temporary directory, `/mnt/tmp`, as desired.

879 3. Unmount the temporary directory and lock the partition:

```
880 $ sudo umount /mnt/tmp
881 $ sudo /greentec/Ubuntu/wvenf /dev/sdb3
```

882 4. Stop the Samba service:

```
883 $ sudo systemctl stop smb.service
```

884 5. Unmount the golden partition:

```
885 $ sudo umount /mnt/golden
```

886 6. Modify the `/etc/fstab` file with the new partition name and save the file:

```
887 /dev/sdb3 /mnt/golden fuseblk
888 rw,nosuid,nodev,relatime,user_id=0,group_id=0,allow_other,blksize
889 =4096 0 0"
```

890 7. Re-mount all partitions, start the Samba service, and remove the temporary directory:

```
891 $ sudo mount -a
892 $ sudo systemctl stop smb.service
893 $ sudo rmdir -r /mnt/tmp
```

894 **2.4.3.3 Samba**

895 1. Add local user accounts to the appliance for accessing the network file shares and create a
 896 password:

```
897 $ sudo adduser nccoeuser
898 $ sudo smbpasswd -a nccoeuser
```

899 2. Open the file `/etc/samba/smb.conf` and add the following content to the end of the
 900 file to create the individual shares:

```
# GreenTec-USA ForceField Share
strict sync=no

# OSIsoft PI historian and database backups
[ForceField]
```

```

browsable = yes
guest ok = no
path = /mnt/forcefield
read only = no
writeable = yes
case sensitive = yes

# GreenTec-USA Golden WORMDisk Share
[golden]
browsable = yes
guest ok = no
path = /mnt/golden
read only = no
writeable = yes
case sensitive = yes

```

901 3. Restart Samba:

902 \$ sudo systemctl restart smbd.service

903 *2.4.3.4 OS/soft PI Server and Database Backups*

904 Create the scheduled backup task to backup PI Data Archive files. The script automatically inserts the
905 current datetime stamp into the filename of each file copied to the ForceField drive. Follow these steps:

906 1. On the server containing the PI Data Archive, open a command prompt with Administrator
907 privileges.

908 2. Change to the PI\adm directory:

909 > cd /d "%piserver%adm"

910 3. Create the backup directory, and start the Windows scheduled task to perform the backup:

911 > pibackup h:\PIBackup -install

912 Create a scheduled task to copy the backup files to the ForceField HDD. Follow these steps:

913 1. Open the Task Scheduler and create a new scheduled task to rename, timestamp, and copy the
914 backup files to the ForceField HDD:

915 Trigger: At 3:30 AM every day

916 Action: Start a Program

917 Program/script:

918 C:\Windows\System32\WindowsPowerShell\v1.0\powershell.exe

919 Add arguments (optional): -Command { Get-ChildItem -Path

920 "h:\PIBackup\arc\" | foreach { copy-item -path \$_.FullName) -

921 destination "\\10.100.1.7\ForceField\\$(Get-Date -f yyyy-MM-

922 dd_HHMMss)_\$_(\$_.name) " } }

923 2.5 Microsoft Azure Defender for IoT

924 Microsoft Azure Defender for IoT, based on technology acquired via CyberX, consists of a single
 925 appliance containing the sensor and application interface integrated into Build 4 to meet BAD, hardware
 926 modification, firmware modification, and software modification capabilities. The Microsoft Azure
 927 Defender for IoT implementation utilizes passive monitoring and protocol analysis to support
 928 cybersecurity monitoring and threat detection.

929 2.5.1 Host and Network Configuration

930 Microsoft Azure Defender for IoT was installed and configured to support the CRS environment as part
 931 of Build 4. The overall build architecture is provided in [Figure B-4](#). The Microsoft Azure Defender for IoT
 932 specific components are in Table 2-9.

933 Table 2-9 Microsoft Azure Defender IoT Deployment

Name	System	OS	CPU	Memory	Storage	Network
Azure Defender for IoT	Dell OEMR XL R340	Ubuntu 18.04	Intel Xeon E-2144G	32 GB	3x 2 TB Drives RAID-5	Testbed LAN 10.100.0.61

934 2.5.2 Installation

935 The Microsoft Azure Defender for IoT (Version 10.0.3) appliance was preinstalled with the operating
 936 system and application. The appliance is mounted in a rack with power and network interfaces
 937 connected to the Testbed LAN on the Eth0 port along with the SPAN connection on the expansion
 938 network interface board.

939 2.5.3 Configuration

940 To configure the Microsoft Azure Defender for IoT platform, follow these steps:

- 941 1. Set the Network Configuration:
 - 942 a. Using either SSH, iDRAC, or the KVM Console connections on the appliance, establish
 943 shell access to the appliance.
 - 944 b. From the console, enter the following command:
 945 `$sudo cyberx-xsense-network-reconfigure`
 - 946 c. The system will walk through a series of network options (Figure 2-25) that are set as
 947 follows:
 - 948 i. **IP Address:** "10.100.0.61"
 - 949 ii. **Subnet Mask:** "255.255.255.0"
 - 950 iii. **DNS:** "10.100.0.17"

- 951 iv. **Default Gateway:** "10.100.0.1"
- 952 v. **Hostname:** *Not set*
- 953 vi. **Input Interface(s):** "enp3s0f3, enp1s0f2, enp3s0f1, enp1s0f0, enp1s0f3, enp3s0f2,
954 enp1s0f1, enp3s0f0"
- 955 vii. **Bridge Interface(s):** *Not Set*

956 **Figure 2-25 Azure Defender for IoT SSH Session for Network Configuration**

```

IP: 10.100.0.61
SUBNET: 255.255.255.0
GATEWAY: 10.100.0.1
UID: 4C4C4544-0050-4C10-8034-C2C04F363133

Hint: Num Lock on

xsense login: cyberx
Passuord:
Last login: Fri Feb 12 13:23:21 UTC 2021 on tty1

  System information as of Fri Feb 12 13:24:03 UTC 2021

  System load:  2.15          Processes:           212
  Usage of /:   1.6% of 1.56TB Users logged in:     0
  Memory usage: 39%         IP address for eno1: 10.100.0.61
  Swap usage:   0%          IP address for docker0: 172.17.0.1

  [V] [O]
  [M] [I] [C] [I] [T] [O] [X] [N] [O] [T] [E]
  [I] [L] [L] [I] [C] [I] [T] [O] [X] [N] [O] [T] [E]

cyberx@xsense:~$ sudo cyberx-xsense-network-reconfigure
[sudo] password for cyberx:
starting "/usr/local/bin/cyberx-xsense-network-reconfigure"

management network IP address is set to "10.100.0.61". Edit? [y/N]: n
subnet mask is set to "255.255.255.0". Edit? [y/N]: n
DNS is set to "10.100.0.17". Edit? [y/N]: n
default gateway IP address is set to "10.100.0.1". Edit? [y/N]: n
hostname is set to "". Edit? [y/N]: n
input interface(s) is set to "enp3s0f3,enp1s0f2,enp3s0f1,enp1s0f0,enp1s0f3,enp3s0f2,enp1s0f1,enp3s0f0". Edit? [y/N]: n
bridge interface(s) is set to "". Edit? [y/N]: n

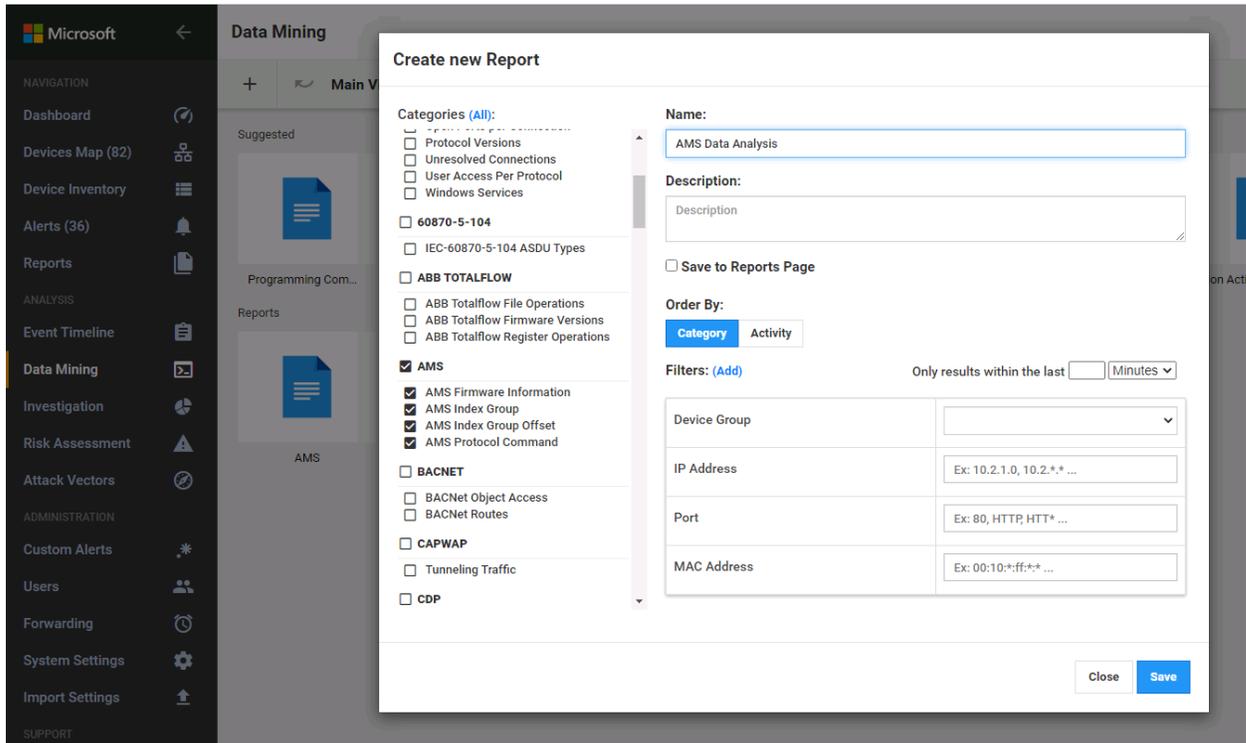
WARNING! to apply settings, system will be rebooted and you will be disconnected from your active session. Are you sure you wish
to proceed? [Y/n]:

```

- 957 2. Create AMS Protocol report as a data mining tool:
- 958 a. Login to the application web interface and click **Data Mining** in the left menu navigation.
- 959 b. Click the + sign and click **New Report**. In the **Create New Report** panel set the following
960 settings (Figure 2-26):
- 961 i. Under Categories select **AMS** to automatically select the sub-elements, including:
- 962 1) AMS Firmware Information
- 963 2) AMS Index Group
- 964 3) AMS Index Group Offset

- 965 4) AMS Protocol Command
- 966 ii. Enter "AMS Data Analysis" as the name for the report.
- 967 iii. Click **Save**.

968 Figure 2-26 Azure Defender for IoT Create New Data Mining Report for AMS Protocol Information



- 969 3. Create AMS – Custom Alert Rules
- 970 For this effort, the CRS PLC is configured to run using firmware version 3.1.4022 as the approved
- 971 production firmware version. To detect changes to the approved version, custom alert rules are
- 972 created to monitor for deviations from the approved version numbers through the AMS protocol
- 973 messages over the network.
- 974 a. Click **Horizon** on the left menu navigation.
- 975 b. Select **AMS > Horizon Customer Alert** under the Plugin Options on the left menu.
- 976 c. Create Custom Alert to Detect Change in PLC Firmware Major Build Number (Figure
- 977 2-27):
- 978 i. Enter "PLC Firmware Major Build Mismatch" as the title for the custom alert.
- 979 ii. Enter "PLC {AMS_server_ip} Firmware Major Version Build Mismatch Detected"
- 980 as the message to display with the alert.
- 981 iii. Set the following conditions:

996 **Figure 2-28 Azure Defender for IoT Custom Alert for Firmware Minor Version Number Change**

AMS - Custom Alert Rules

Trigger custom AMS alerts based on traffic detected on this Sensor.

Title: PLC Firmware Minor Build Mismatch

Message: PLC {AMS.server_ip} Firmware Minor Build Mismatch Detected

Use {} to add variables to the message

Conditions:

Variable	Operator	Value
AMS.server_ip	==	32322355
AND		
AMS.minor	~=	1

CLEAR SAVE

- 997
- 998 e. Create the custom alert to detect change in the PLC Firmware Build Version (Figure
- 999 2-29):
 - 1000 i. Enter "PLC Firmware Build Version Mismatch" as the Title for the custom alert.
 - 1001 ii. Enter "PLC {AMS_server_ip} Build Version Mismatch Detected" as the message to
 - 1002 display with the alert:
 - 1003 iii. Set the following conditions:
 - 1004 1) **AMS_server_ip == 323223550** (Note: this is the PLC IP address
 - 1005 192.168.0.30 in Integer format).
 - 1006 2) **AND AMS_version_build ~= 4022**

1007 **Figure 2-29 Azure Defender for IoT Custom Alert for Firmware Build Version Number Change**

AMS - Custom Alert Rules

Trigger custom AMS alerts based on traffic detected on this Sensor.

Title: PLC Firmware Build Version Mismatch

Message: PLC {AMS.server_ip} Build Version Mismatch Detected

Use {} to add variables to the message

Conditions:

Variable	Operator	Value
AMS.server_ip	==	32322355
AND		
AMS.version_build	~=	4022

CLEAR SAVE

1008

1009 2.6 OSIsoft PI Data Archive

1010 The OSIsoft product included in this practice guide is Process Information (PI), which is used to collect,
1011 store, analyze, and visualize testbed data. The product was utilized in Builds 1, 2, 3, and 4 to meet the
1012 Historian capability by collecting and storing testbed data and the BAD capability by alerting when
1013 activity deviates from a baseline.

1014 OSIsoft PI is a suite of software applications for capturing, analyzing, and storing real-time data for
1015 industrial processes. Although the PI System is typically utilized as a process historian, the PI System is
1016 also utilized to collect, store, and manage data in real time. Interface nodes retrieve data from disparate
1017 sources to the PI Server, where the PI Data Archive resides. Data is stored in the data archive and is
1018 accessible in the assets defined in the Asset Framework (AF). Data is accessed either directly from the
1019 data archive or from the AF Server by using tools in the PI visualization suite.

1020 2.6.1 Host and Network Configuration

1021 PI was installed on virtual machines hosted on hypervisors located in the DMZ and CRS networks. The
1022 virtual machine details and resources are provided in Table 2-10, Table 2-11 and, Table 2-12. The overall
1023 build architectures utilizing PI are described in Section 4.5 in Volume B.

1024 **Table 2-10 OSIsoft PI Domain Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
DMZ Historian	Virtual Machine	Microsoft Windows Server 2016	4x Intel Xeon E3-1240	8 GB	Boot: 80 GB PI Data: 170 GB	DMZ 10.100.1.4

1025

1026 **Table 2-11 OSIsoft PI CRS Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
CRS Local Historian	Virtual Machine	Microsoft Windows Server 2016	4x Intel Xeon E5-2407	16 GB	Boot: 80 GB PI Data: 170 GB	CRS Supervisory LAN 192.168.0.21

1027

1028 **Table 2-12 OSIsoft PI PCS Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
PCS Local Historian	Virtual Machine	Microsoft Windows Server 2008 R2	1x Intel i5-4590	2 GB	50 GB	PCS VLAN 2 172.16.2.14

1029

1030 2.6.2 Installation

1031 PI was previously installed in the testbed as part of the *NISTIR 8219: Securing Manufacturing Industrial*
1032 *Control Systems: Behavioral Anomaly Detection*,
1033 <https://www.nccoe.nist.gov/sites/default/files/library/mf-ics-nistir-8219.pdf>. The installation for this
1034 project involved upgrading the existing CRS Local Historian and DMZ Historian VMs to Microsoft
1035 Windows Server 2016, and subsequently upgrading all the PI software components. Step-by-step
1036 instructions for each PI component installation are not included for brevity. Detailed instructions
1037 provided by the vendor can be found on the OSIsoft Live Library: <https://livelibrary.osisoft.com/>.

1038 **DMZ Historian Server**

1039 The following software is installed on the DMZ Historian server:

- 1040 ▪ Microsoft SQL Server 2019 Express 15.0.2080.9
- 1041 ▪ PI Server 2018 (Data Archive Server, Asset Framework Server)
- 1042 ▪ PI Server 2018 SP3 Patch 1
- 1043 ▪ PI Interface Configuration Utility version 1.5.1.10
- 1044 ▪ PI to PI Interface version 3.10.1.10
- 1045 ▪ PI Interface for Ramp Soak Simulator Data 3.5.1.12
- 1046 ▪ PI Interface for Random Simulator Data 3.5.1.10
- 1047 ▪ PI Connector Relay version 2.6.0.0
- 1048 ▪ PI Data Collection Manager version 2.6.0.0
- 1049 ▪ PI Web API 2019 SP1 version 1.13.0.6518

1050 **CRS Local Historian Server (Collaborative Robotics System)**

1051 The following software is installed on the CRS Local Historian server:

- 1052 ▪ Microsoft SQL Server 2019 Express 15.0.2080.9
- 1053 ▪ PI Asset Framework Service 2017 R2 Update 1
- 1054 ▪ PI Data Archive 2017 R2A
- 1055 ▪ PI Server 2018 SP3 Patch 1
- 1056 ▪ PI Interface Configuration Utility version 1.5.1.10
- 1057 ▪ PI to PI Interface version 3.10.1.10
- 1058 ▪ PI Interface for Ramp Soak Simulator Data 3.5.1.12
- 1059 ▪ PI Interface for Random Simulator Data version 3.5.1.10
- 1060 ▪ PI Interface for Performance Monitor version 2.2.0.38
- 1061 ▪ PI Ping Interface version 2.1.2.49
- 1062 ▪ PI Interface for Modbus ReadWrite version 4.3.1.24
- 1063 ▪ PI Interface for SNMP ReadOnly version 1.7.0.37

- 1064 ▪ PI TCP Response Interface version 1.3.0.47
- 1065 ▪ PI Processbook 2015 R3 Patch 1 version 3.7.1.249
- 1066 ▪ PI Vision 2019 Patch 1 version 3.4.1.10
- 1067 ▪ PI System Connector version 2.2.0.1

1068 **PCS Local Historian (Process Control System Historian)**

- 1069 ▪ Rockwell FactoryTalk Historian SE version 1.00

1070 **2.6.3 Configuration**

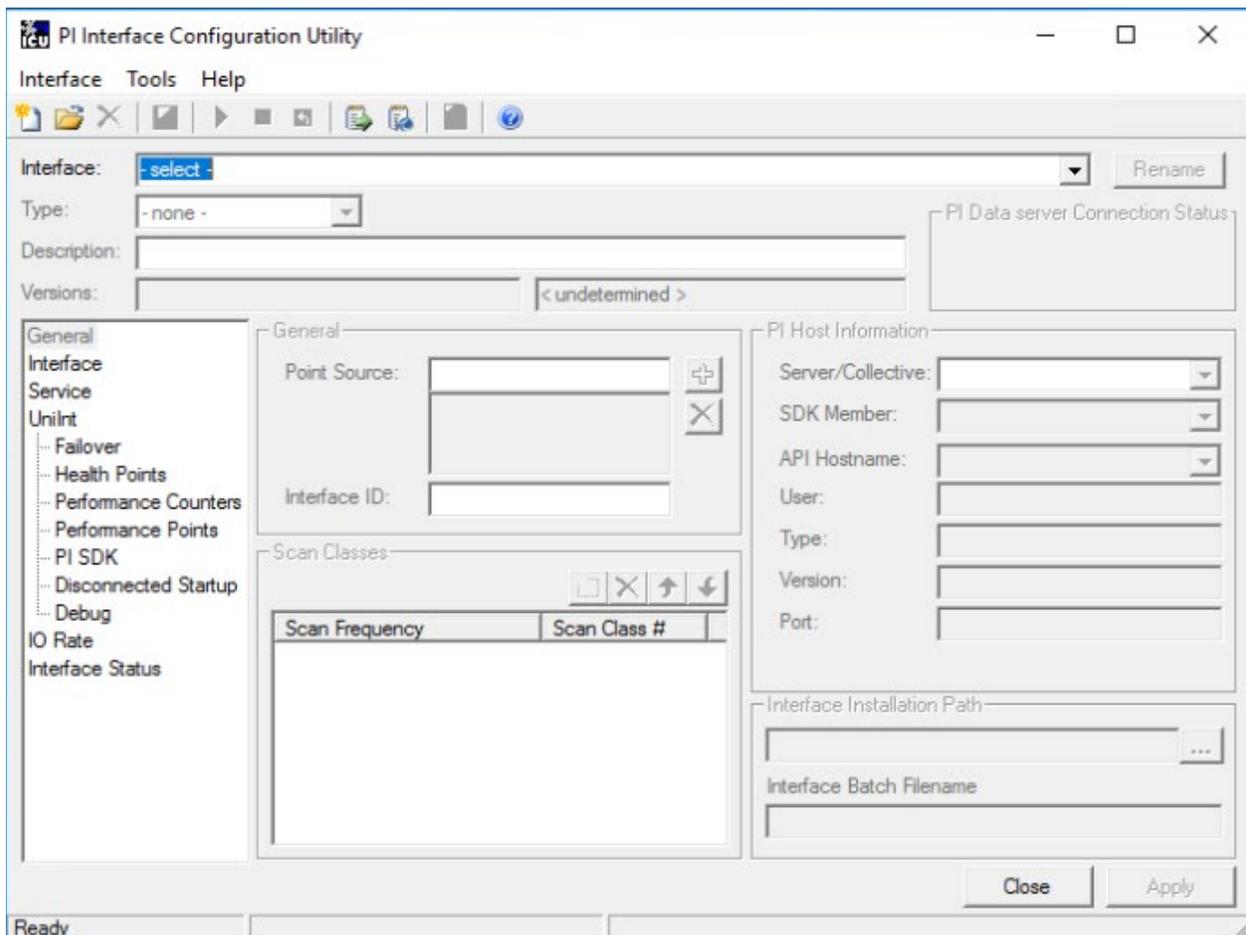
1071 The following sections describe how to configure select PI components to enable the capabilities
1072 described in this guide. Configurations for the other PI components are not included for brevity.

1073 **2.6.3.1 PI to PI Interface (PCS)**

1074 The PCS uses the Rockwell FactoryTalk Historian to collect, store, and analyze historical process data.
1075 The PI to PI Interface is used to duplicate the process data to the DMZ Historian server. The following
1076 steps describe how to configure the PI to PI Interface to collect data from the Rockwell FactoryTalk
1077 Historian.

- 1078 1. On the DMZ Historian server, launch the **PI Interface Configuration Utility** as shown in Figure
1079 2-30 from the Start menu and sign in with the local administrator account.

1080 Figure 2-30 Screenshot of the PI Interface Configuration Utility before the Interface is configured.



1081

1082

- 1083 2. On the top menu, click **Interface > New Windows Interface Instance from BAT File...**
- 1084 3. Navigate to **E:\Program Files (x86)\PIPC\Interfaces\PIttoPI** and select the file **PIttoPI.bat_new**.
- 1085 4. In the “Select Host PI Data server/collective” dialog box, select **PI-DMZ** from the drop-down
- 1086 menu and click **OK**.
- 1087 5. In the left navigation panel select **PIttoPI**. In the Source host textbox, enter "172.16.2.4".
- 1088 6. In the left navigation panel, select **Service**. In the “Create / Remove” section click the **Create**
- 1089 button. Click **Yes** in the dialog box.
- 1090 7. Enter the commands `net start PIttoPI` and `net stop PIttoPI` in the files
- 1091 **pisrvsitestart.bat** and **pisrvsitestop.bat** files, respectively. Save and close the files.
- 1092 8. At the bottom of the **PI Interface Configuration Utility** click the **Apply** button. On top menu bar
- 1093 click the green play button  to start the service.

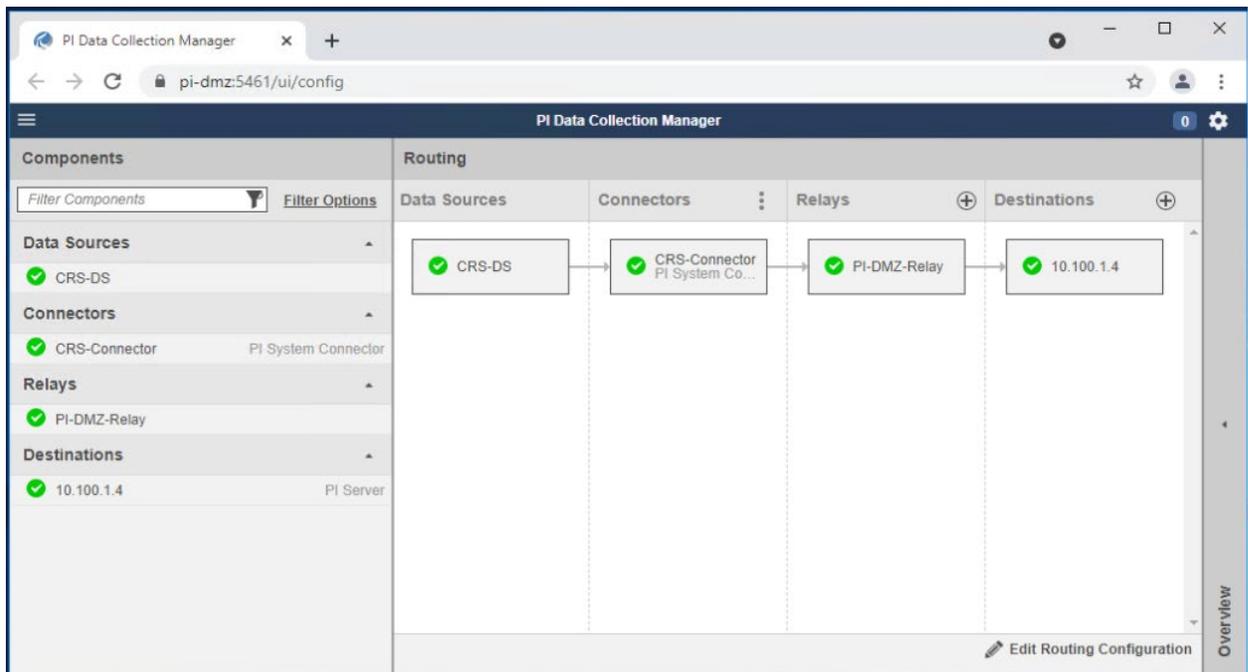
DRAFT

- 1094 9. Close the **PI Interface Configuration Utility**. The interface is now configured to pull tags from the
1095 Rockwell Historian.

1096 *2.6.3.2 PI System Connector (CRS)*

1097 The PI System Connector is used to duplicate process data on the DMZ Historian from the CRS Local
1098 Historian server. The following steps describe how to configure the PI-to-PI Interface to collect data
1099 from the OSIsoft PI Server.

1100 **Figure 2-31 Screenshot of the PI Data Collection Manager Displaying Green Checkmarks After the PI**
1101 **System Connector is Properly Configured**



- 1102
- 1103 1. On the DMZ Historian server, launch the **PI Data Collection Manager** as shown in Figure 2-31
1104 from the Start menu and sign in with the local administrator account.
- 1105 a. Click + on the Relays column to add a new connector relay. Use the following settings:
- 1106 b. Name: PI-DMZ-Relay
- 1107 c. Address: 10.100.1.4
- 1108 d. Port: 5460
- 1109 2. User Name: `.\piconnrelay_svc`
- 1110 3. Click **Save Settings** to add the connector relay.
- 1111 4. Click + **Add Destination** to add the target PI Data Archive and PI AF Server. Use the following
1112 settings:
- 1113 a. Name: 10.100.1.4

- 1114 b. PI Data Archive Address: 10.100.1.4
- 1115 c. AF Server: 10.100.1.4
- 1116 5. Click **Save Settings** to add the destination.
- 1117 6. On the CRS Local Historian server, open the **PI System Connector Administration** from the Start
1118 menu and sign in with the local administrator account.
- 1119 7. Click **Set up Connector** to create a new connector.
- 1120 8. Use the following information to request registration:
- 1121 a. Registration Server Address: https://PI-DMZ:5460
- 1122 b. Registration Server User Name: piconnrelay_svc
- 1123 c. Registration Server Password:
- 1124 d. Description: Registration to PI-DMZ
- 1125 9. Click **Request Registration** to send the request to the DMZ Historian server.
- 1126 10. On the DMZ Historian server, open the **PI Data Collection Manager** from the Start menu and
1127 sign in with the local administrator account.
- 1128 11. Click **Untitled Connector 1** and click **Approve This Registration and Configure** to approve the PI
1129 System Connector registration.
- 1130 12. In the **Untitled Connector 1** details panel, click **Edit**.
- 1131 13. Use the following information to create the CRS-Connector connector:
- 1132 a. Name: CRS-Connector
- 1133 b. Description: Registration to PI-DMZ
- 1134 14. Click **Save Settings** to create the CRS-Connector.
- 1135 15. Click **CRS-Connector** in the **Connectors** column. On the **Overview** panel click **CRS-Connector: No**
1136 **Data Sources** option to create the data source.
- 1137 16. On the **CRS-Connector** Connector Details in the **Overview** panel, click **+ Add Data Source**.
- 1138 17. In the **Data Source Settings** window, use the following settings:
- 1139 a. Name: CRS-DS
- 1140 b. Source AF Server: PI-Robotics
- 1141 c. Source AD Database: TestbedDatabase
- 1142 d. Select **Collect All Data from this Entire Database**.
- 1143 18. Click **Save** to save the data source.

- 1144 19. Click 10.100.1.4 in the **Destination** column of the **Routing** panel and then click **Data** in the
1145 **10.100.1.4 Destination Details** panel to configure the destination database for the CRS-
1146 Connector.
- 1147 20. In the **10.100.1.4 Destination Details** panel, change from **Change Default Settings for new**
1148 **connectors** to "CRS-Connector" and then click **Edit Destination Data Settings**.
- 1149 21. In the **10.100.1.4 Destination Details** of the **Overview** panel, use the following settings:
- 1150 a. Change the connector to **CRS-Connector**.
 - 1151 b. Database: CRS-backup
 - 1152 c. Click on **Elements** and it will change <select a path using the tree below> to **\$Elements**
 - 1153 d. Use default settings in **Root AF Elements** and **Point Names**.
 - 1154 e. **Create root Element CRS-Connector** checkbox: Checked
 - 1155 f. **Prefix Point CRS-Connector** checkbox: Checked
- 1156 22. Click **Save Destination Data Settings** to save the configuration.
- 1157 23. Click the white space in the **Routing** panel.
- 1158 24. Click **CRS-Connector: No Relays** in the **Overview** panel.
- 1159 25. Select the **PI-DMZ-Relay** checkbox in the **Routing** panel.
- 1160 26. Click the white space in the **Routing** panel again, then **Click PI-DMZ-Relay: No Destination** to
1161 add the routing between relays and destinations.
- 1162 27. Select the **10.100.1.4** checkbox to add the routing between the relay and the destination.
- 1163 28. Click **Save Configuration**.
- 1164 29. In the **Save Routing and Data Configuration** window, select **Save and Start All Components** to
1165 continue.
- 1166 30. Each box should now contain a green checkmark (i.e., Data Sources, Connectors, Relays, and
1167 Destinations). The elements in the AF database "testbeddatabase" on CRS Local Historian server
1168 is now replicated to AF database "CRS-backup" on the DMZ Historian server.
- 1169 31. Finally, create a Windows firewall rule to open the inbound ports 5460, 5461, 5471, and 5472.

1170 *2.6.3.3 PI Asset Template Analysis Functions and Event Frames*

1171 Analysis functions and event frame templates were created to generate alerts in the PLC asset template
1172 when their respective anomalous events are detected. When an analysis function result is TRUE, an
1173 event frame is generated from the event frame template and ends when the analysis function result is
1174 FALSE or per a user-defined function. The following steps describe how the "Station Mode Error"
1175 analysis function and event frame template were created and used in Scenario 10.

- 1176 1. On the CRS Local Historian server, open the **PI System Explorer** by navigating to **Start Menu > PI**
 1177 **System > PI System Explorer**.
- 1178 2. On the left navigation panel, select **Library**.
- 1179 3. In the navigation tree in the **Library** panel, select **Templates > Event Frame Templates**.
- 1180 4. Right click in the whitespace of the **Element Templates** window and select **New Template**.
- 1181 a. Enter the following:
- 1182 b. Name: Station Mode Error
- 1183 c. Description: CRS Workcell machining station mode error
- 1184 5. Naming Pattern: ALARM-%ELEMENT%.%TEMPLATE%.%STARTTIME:yyyy-MM-dd
 1185 HH:mm:ss.fff%
- 1186 6. In the navigation tree in the **Library** panel, select **Templates > Element Templates >**
 1187 **Machining_Station**.
- 1188 7. In the **Machining_Station** panel select the **Analysis Templates** tab and click **Create a new**
 1189 **analysis template**.
- 1190 8. Enter the name “Station Mode Error” in the **Name** textbox, enter a description of the analysis in
 1191 the Description textbox, and select the option “Event Frame Generation” for the **Analysis Type**.
- 1192 9. Select “Station Mode Error” in the **Event Frame** template drop-down menu.
- 1193 10. In the **Expression** field for “StartTrigger1”, enter the expression:
- 1194 'RawMode' < 0 OR 'RawMode' > 1;
- 1195 11. Click the **Add...** drop-down menu and select **End Trigger**, and enter the expression:
- 1196 ('RawMode' > 0 AND 'RawMode' < 1)
- 1197 12. Select the “Event-Triggered” option for the **Scheduling** type.
- 1198 13. Click the **Check In** button on the top menu to save all changes to the database.

1199 *2.6.3.4 PI Web API*

1200 The PI Web API is used by Dragos to collect event frames from the DMZ Historian server. After
 1201 completing the installation of the PI Web API, the “Change PI Web API Installation Configuration” dialog
 1202 displays. The following steps describe how to configure the Web API on the DMZ Historian server.

- 1203 1. In the **Telemetry** section, verify the checkbox option and click **Next**.
- 1204 2. In the **Configuration Store** section, select "PI-ROBOTICS" in the Asset Server drop-down menu
 1205 and click Connect. Leave the default instance name.
- 1206 3. In the **Listen Port** section, verify port 443 is entered in the **Communication Port Number**
 1207 textbox and check the **Yes, please create a firewall Exception for PI Web API** checkbox.

- 1208 4. In the **Certificate** section, click **Next** to continue and use the self-signed certificate or select
1209 **Change** to modify the certificate.
- 1210 5. In the **API Service** section, leave the default service `NT Service\piwebapi` and click **Next**.
- 1211 6. In the **Crawler Service** section, leave the default `service NT Service\picrawler` and
1212 click **Next**.
- 1213 7. In the **Submit URL** section, enter the URL of the DMZ Historian server Web API service:
1214 `https://pi-dmz/piwebapi/`. Click **Next**.
- 1215 8. In the **Review Changes** section, verify all the configuration settings, check the checkbox **Accept**
1216 **all the configurations**, and click **Next**.
- 1217 9. Click **Finish** to complete the configuration.

1218 *2.6.3.5 Firmware Integrity Checking*

1219 Software was developed to demonstrate the ability of PI to obtain device and firmware data from a
1220 Beckhoff PLC for integrity checking purposes. A new PLC task was programmed to periodically query its
1221 operating system for hardware and software telemetry and make it available via Modbus TCP. PI will
1222 query these Modbus registers and use analysis functions to generate event frames if any tags do not
1223 match their expected values.

1224 It is important to note that this capability was developed to demonstrate a method of maintaining
1225 visibility of PLC hardware and firmware version numbers for integrity purposes and is not secure or
1226 infallible. If a malicious actor takes control of the PLC, the hardware and firmware versions provided by
1227 the PLC can be spoofed.

1228 The following steps describe how to sequentially configure this capability across multiple systems and
1229 software. Only one system or software is described in each section.

1230 **Beckhoff PLC Modbus TCP Server**

1231 The base Modbus TCP server configuration file only allows one PLC task to write to the registers. The
1232 following steps describe how to modify the configuration to allow two PLC tasks to write to the Modbus
1233 TCP server input registers.

- 1234 1. Log in to the Windows CE Desktop of the Beckhoff PLC and open the XML file:
1235 `\TwinCAT\Functions\TF6250-Modbus-TCP\Server\TcModbusSrv.xml`
- 1236 2. Modify the `<InputRegisters> ... </InputRegisters>` section to the following:

```

<InputRegisters>
  <MappingInfo>
    <AdsPort>851</AdsPort>
    <StartAddress>32768</StartAddress>
    <EndAddress>32895</EndAddress>
    <VarName>GVL.mb_Input_Registers</VarName>
  </MappingInfo>
  <MappingInfo>
    <AdsPort>852</AdsPort>
    <StartAddress>32896</StartAddress>
    <EndAddress>33023</EndAddress>
    <VarName>GVL.mb_Input_Registers</VarName>
  </MappingInfo>
</InputRegisters>

```

1237

1238 3. Save and close the file.

1239 4. Restart the PLC.

1240 The Modbus TCP server will now have two register address ranges: 128 addresses for the PLC task at
 1241 port 851, and 128 addresses for the PLC task at port 852.

1242 **Beckhoff PLC Project**

1243 A new PLC task must be created to perform the integrity checking and write the data to the Modbus TCP
 1244 registers. The following steps describe how to create and configure the new task.

1245 1. On the engineering workstation, open the **TwinCAT XAE Shell** by navigating to **Start Menu >**
 1246 **Beckhoff > TwinCAT XAE Shell** and open the current PLC project.

1247 2. In the **Solution Explorer**, right click **PLC** and select **Add New Item...**

1248 3. In the **Add New Item** dialog box, select **Standard PLC Project**, enter the name
 1249 `FirmwareIntegrityCheck` in the **Name** textbox, and click **Add**.

1250 4. In the **Solution Explorer**, double click **SYSTEM > Tasks > PLCTask1**. Verify the **Auto Start**
 1251 checkbox is checked and change the **Cycle Ticks** textbox to 100 ms.

1252 5. In the **Solution Explorer**, right click **PLC > FirmwareIntegrityCheck > References** and click **Add**
 1253 **library...** In the dialog box, select the library **System > Tc2_System** and click **OK**.

1254 6. In the **Solution Explorer**, right click **PLC > GVLs** and click **Add > Global Variable List**. In the dialog
 1255 box enter the name `GVL` in the **Name** textbox and click **Open**.

1256 7. In the **Editor Window**, enter the following code:

```

VAR_GLOBAL
  mb_Input_Registers : ARRAY [0..127] OF WORD;
END_VAR

```

1257

1258 8. In the **Solution Explorer**, right click **PLC > FirmwareIntegrityCheck > POU** and select **Add > POU**.
1259 In the **Add POU** dialog box, enter the name `GetSystemInfo`, select the type **Function Block**,
1260 select the **Implementation Language** `Structured Text (ST)` and click **Open**.

1261 9. In the **Editor Window**, enter the following code in the **Variables** section:

```
// Gathers PLC information for system integrity checking
// (e.g., PLC serial number, TwinCAT version).
FUNCTION_BLOCK GetSystemInfo
VAR_INPUT
    NetId : T_AmsNetId; // AMS network ID of the PLC
END_VAR
VAR_OUTPUT
    HardwareSerialNo : WORD; // Serial number of PLC
    TwinCATVersion : WORD; // Version number of TwinCAT
    TwinCATRevision : WORD; // Revision number of
TwinCAT
    TwinCATBuild : WORD; // Build number of TwinCAT
END_VAR
VAR
    DeviceData : FB_GetDeviceIdentification; //PLC data
struct
    Timer : TON; // Timer to trigger the scan
    Period : TIME := T#5M; // Amount of time between
each scan
    State : INT := 0; // Function block state
END_VAR
```

1262

1263 10. In the **Editor Window**, enter the following code in the **Code** section:

```

CASE state OF
  0:
    // Start a new request for device
    identification
    DeviceData(bExecute:=TRUE, tTimeout:=T#100MS,
sNetId:=NetId);
    // Switch to the next state once the request
    completes
    IF DeviceData.bBusy = FALSE THEN
      state := 10;
    END_IF
  10:
    // Store the interesting data into our internal
    variables
    HardwareSerialNo :=
STRING_TO_WORD(DeviceData.stDevIdent.strHardwareSerialNo);
    TwinCATVersion :=
STRING_TO_WORD(DeviceData.stDevIdent.strTwinCATVersion);
    TwinCATRevision :=
STRING_TO_WORD(DeviceData.stDevIdent.strTwinCATRevision);
    TwinCATBuild :=
STRING_TO_WORD(DeviceData.stDevIdent.strTwinCATBuild);
    // Reset the timer and move to the next state
    Timer(IN:= FALSE);
    state := 20;
  20:
    // Make sure the timer is running and change to
    the
    // next state once the period has been reached
    Timer(IN:=TRUE,PT:=Period);
    IF Timer.Q = TRUE THEN
      state := 0;
    END_IF
END_CASE

```

1264

1265

11. Save and close the POU.

1266

12. In the **Solution Explorer**, double click **PLC > FirmwareIntegrityCheck > POU's > MAIN (PRG)**.

1267

13. In the **Editor Window**, enter the following into the **Variables** section (your AMS net ID may

1268

differ from what is shown below):

```

PROGRAM MAIN
VAR
  PLCInfo : GetSystemInfo; // Periodically collects
  PLC data
  SelfNetId : T_AmsNetId := '5.23.219.8.1.1'; // Local
  address
END_VAR

```

1269

1270 14. In the **Editor Window**, enter the following into the **Code** section:

```
// Captures hardware serial numbers and TwinCAT version
// numbers from the PLC and shares them with other
// devices via Modbus TCP.
PLCInfo( NetId:=SelfNetId,
        HardwareSerialNo => GVL.mb_Input_Registers[0],
        TwinCATVersion   => GVL.mb_Input_Registers[1],
        TwinCATRevision  => GVL.mb_Input_Registers[2],
        TwinCATBuild     => GVL.mb_Input_Registers[3]
        );
```

1271

1272 15. Save and close the POU.

1273 16. In the top menu, select **Build > Build Project**. Once the build process completes select **PLC >**
 1274 **Login**. In the **TwinCAT PLC Control** dialog box, select **Login with download**, verify the **Update**
 1275 **boot project** checkbox is checked, and click **OK**. If the PLC code is not running after the
 1276 download completes, select **PLC > Start** in the top menu.

1277 17. The firmware integrity checking code is now running on the Beckhoff PLC. In the top menu
 1278 select **PLC > Logout** and close the TwinCAT XAE Shell.

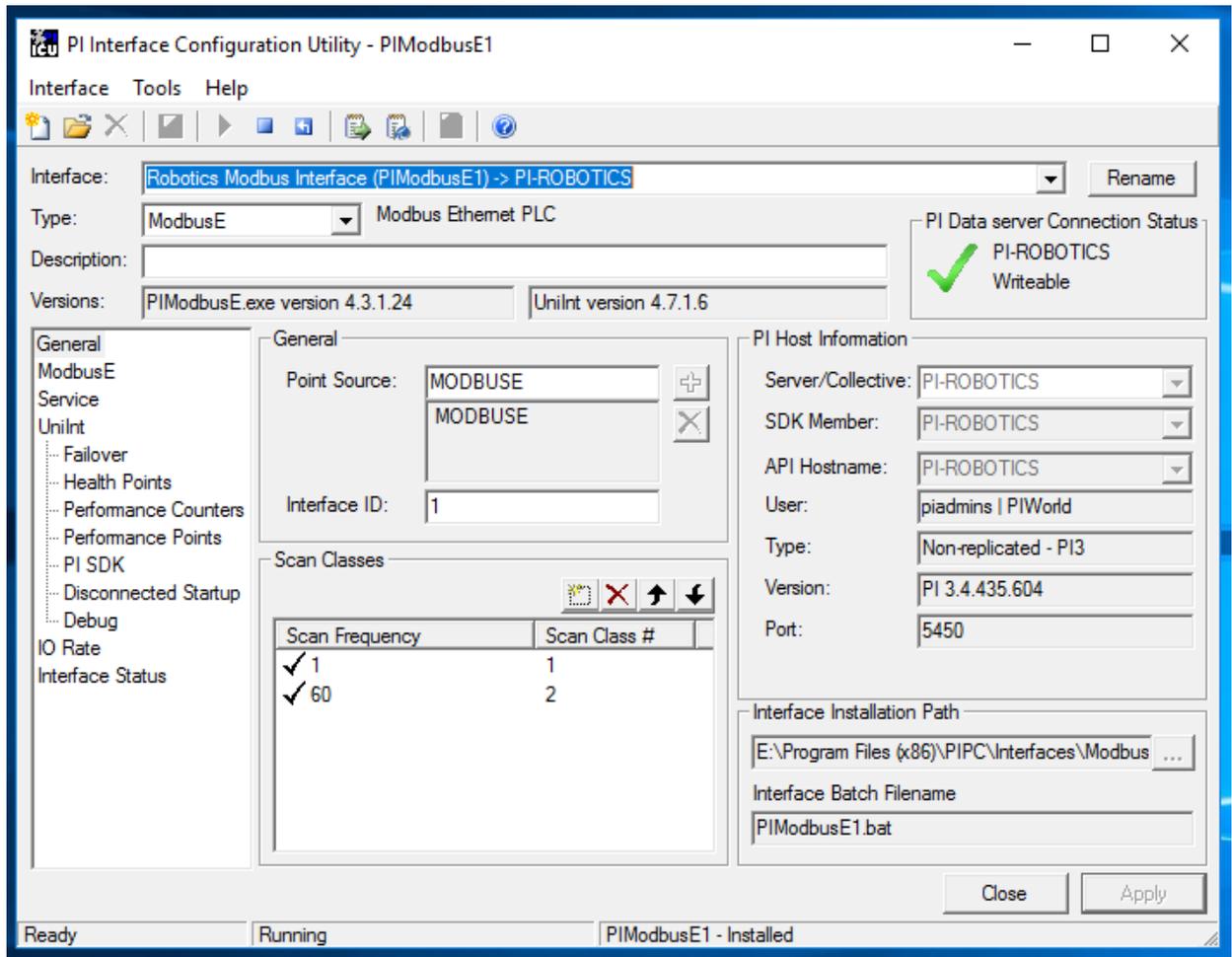
1279 The PLC will now write the hardware serial number and firmware version numbers to the Modbus
 1280 TCP server registers.

1281 **OSisoft PI Points**

1282 The following steps describe how to create the PI points and tags in the CRS Local Historian server and
 1283 duplicate the tags to the DMZ Historian server.

- 1284 1. On the CRS Local Historian server, open the PI Interface Configuration Utility by navigating to
 1285 **Start > All Programs > PI System > PI Interface Configuration Utility**.
- 1286 2. In the **Interface** drop-down menu, select the **Modbus Interface (PIModbusE1)**.
- 1287 3. Select the **General** menu option. In the **Scan Classes** section, click the **New Scan Class** button.
- 1288 4. Set the **Scan Frequency** to "60" and the **Scan Class #** to the next sequential class number as
 1289 shown in Figure 2-32 below.

1290 Figure 2-32 Screenshot of the PI Interface Configuration Utility Showing the Added Scan Class # 2 for
 1291 Polling the PLC Every 60 Seconds



1292

1293

1294 5. Click **Apply** and close the program.

1295 6. On the CRS Local Historian server, open the **PI System Management Tools** by navigating to **Start**
 1296 **Menu > PI System > PI System Management Tools**.

1297 7. In the System Management Tool panel, select **Points > Point Builder**.

1298 8. Create a new tag for the PLC hardware serial number with the following configuration:

1299 a. Name: PLC-HardwareSerialNumber

1300 b. Server: PI-ROBOTICS

1301 c. Descriptor: Hardware serial number of the CRS Beckhoff PLC

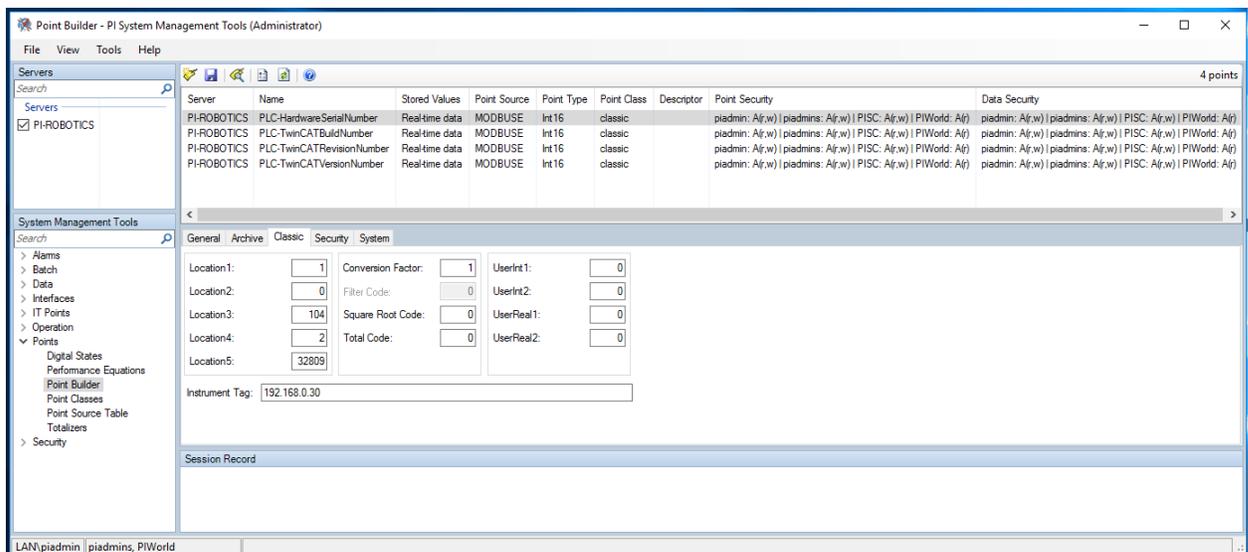
1302 d. Point Source: MODBUS

1303 e. Point Type: Int16

- 1304 f. Location 1: 1
- 1305 g. Location 2: 0
- 1306 h. Location 3: 104
- 1307 i. Location 4: 2
- 1308 j. Location 5: 32897
- 1309 k. Instrument Tag: 192.168.0.30
- 1310 9. Create a new tag for the PLC TwinCAT build number with the following configuration:
 - 1311 a. Name: PLC-TwinCATBuildNumber
 - 1312 b. Server: PI-ROBOTICS
 - 1313 c. Descriptor: Build number of the CRS PLC TwinCAT firmware.
 - 1314 d. Point Source: MODBUS
 - 1315 e. Point Type: Int16
 - 1316 f. Location 1: 1
 - 1317 g. Location 2: 0
 - 1318 h. Location 3: 104
 - 1319 i. Location 4: 2
 - 1320 j. Location 5: 32900
 - 1321 k. Instrument Tag: 192.168.0.30
- 1322 10. Create a new tag for the PLC TwinCAT revision number with the following configuration:
 - 1323 a. Name: PLC-TwinCATRevisionNumber
 - 1324 b. Server: PI-ROBOTICS
 - 1325 c. Descriptor: Revision number of the CRS PLC TwinCAT firmware.
 - 1326 d. Point Source: MODBUS
 - 1327 e. Point Type: Int16
 - 1328 f. Location 1: 1
 - 1329 g. Location 2: 0
 - 1330 h. Location 3: 104
 - 1331 i. Location 4: 2

- 1332 j. Location 5: 32899
- 1333 k. Instrument Tag: 192.168.0.30
- 1334 11. Create a new tag for the PLC TwinCAT version number with the following configuration as shown
- 1335 in Figure 2-33:
- 1336 a. Name: PLC-TwinCATVersionNumber
- 1337 b. Server: PI-ROBOTICS
- 1338 c. Descriptor: Version number of the CRS PLC TwinCAT firmware.
- 1339 d. Point Source: MODBUS
- 1340 e. Point Type: Int16
- 1341 f. Location 1: 1
- 1342 g. Location 2: 0
- 1343 h. Location 3: 104
- 1344 i. Location 4: 2
- 1345 j. Location 5: 32898
- 1346 k. Instrument Tag: 192.168.0.30
- 1347 12. Close the **PI System Management Tools** program. The PI points are now available to the DMZ
- 1348 Historian server via the PI System Connector.

1349 **Figure 2-33 Screenshot of the PI System Management Tools Component After Configuring the PI Points**
 1350 **for PLC Hardware and Firmware Version Number Integrity Checking**



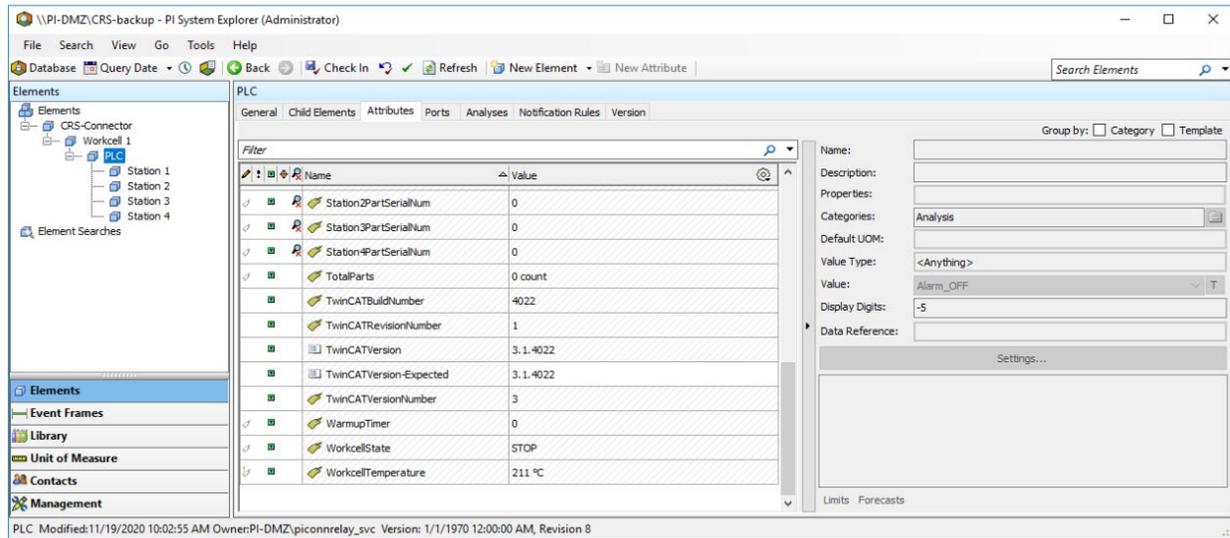
1351

1352

- 1353 13. On the DMZ Historian server, open the **PI System Explorer** by navigating to **Start Menu > PI**
1354 **System > PI System Explorer**.
- 1355 14. On the left navigation panel, select **Library**.
- 1356 15. In the navigation tree in the **Library** panel, select **Templates > Element Templates >**
1357 **PLCTemplate**.
- 1358 16. Open the **Attribute Templates** tab in the **PLCTemplate** panel.
- 1359 17. On the top menu bar, click **New Attribute Template** and create a new attribute for the PLC
1360 hardware serial number by entering the following configuration:
- 1361 a. Name: HardwareSerialNumber
 - 1362 b. Description: Hardware serial number of the CRS Beckhoff PLC.
 - 1363 c. Value Type: Int16
 - 1364 d. Data Reference: PI Point
 - 1365 e. Tag: \\PI-ROBOTICS\PLC-HardwareSerialNumber
- 1366 18. On the top menu bar click **New Attribute Template** and create a new attribute for the expected
1367 hardware serial number by entering the following configuration:
- 1368 a. Name: HardwareSerialNumber-Expected
 - 1369 b. Description: Expected hardware serial number of the CRS Beckhoff
1370 PLC.
 - 1371 c. Value Type: V
 - 1372 d. Data Reference: None
- 1373 19. On the top menu bar click **New Attribute Template** and create a new attribute for the PLC
1374 TwinCAT build number by entering the following configuration:
- 1375 a. Name: TwinCATBuildNumber
 - 1376 b. Description: Build number of the CRS PLC TwinCAT firmware.
 - 1377 c. Value Type: Int16
 - 1378 d. Data Reference: PI Point
 - 1379 e. Tag: \\PI-ROBOTICS\PLC-TwinCATBuild
- 1380 20. On the top menu bar click **New Attribute Template** and create a new attribute for the PLC
1381 TwinCAT revision number by entering the following configuration:
- 1382 a. Name: TwinCATRevisionNumber
 - 1383 b. Description: Revision number of the CRS PLC TwinCAT firmware.

- 1384 c. Value Type: Int16
 - 1385 d. Data Reference: V
 - 1386 e. Tag: \\PI-ROBOTICS\PLC-TwinCATRevision
21. On the top menu bar click New Attribute Template and create a new attribute for the PLC TwinCAT version number by entering the following configuration:
- 1389 a. Name: TwinCATVersionNumber
 - 1390 b. Description: Version number of the CRS PLC TwinCAT firmware.
 - 1391 c. Value Type: Int16
 - 1392 d. Data Reference: PI Point
 - 1393 e. Tag: \\PI-ROBOTICS\PLC-TwinCATVersion
22. On the top menu bar click New Attribute Template and create a new attribute for the string representation of the version, revision, and build numbers by entering the following configuration:
- 1397 a. Name: TwinCATVersion
 - 1398 b. Description: Version number of the CRS PLC TwinCAT firmware.
 - 1399 c. Value Type: String
 - 1400 d. Data Reference: String Builder
 - 1401 e. String:
 - 1402 'TwinCATVersionNumber';.;'TwinCATRevisionNumber';.;'TwinCAT
 - 1403 BuildNumber';
23. On the top menu bar click New Attribute Template and create a new attribute for the PLC expected TwinCAT version number by entering the following configuration as shown in Figure 2-34:
- 1407 a. Name: TwinCATVersion-Expected
 - 1408 b. Description: Expected version number of the CRS PLC TwinCAT
 - 1409 firmware.
 - 1410 c. Value Type: String
 - 1411 d. Data Reference: None
- 1412 The PI points are now available as PLC attributes in the Asset Framework on the DMZ Historian server.

1413 Figure 2-34 Screenshot of PI System Explorer Displaying some Attributes of the PLC Element. Attributes
 1414 for the TwinCAT version number are visible in the list.



1415

1416 OSIsoft PI Analyses and Event Frames

1417 The following steps describe how to create the PI analyses and event frame templates to generate event
 1418 frames when the hardware or firmware version numbers do not match the expected values.

1419 1. In the navigation tree in the **Library** panel, select **Templates > Event Frame Templates**.

1420 2. On the top menu bar click **New Template** and enter the following configuration as shown in
 1421 Figure 2-35:

1422 a. Name: Hardware Serial Number Mismatch

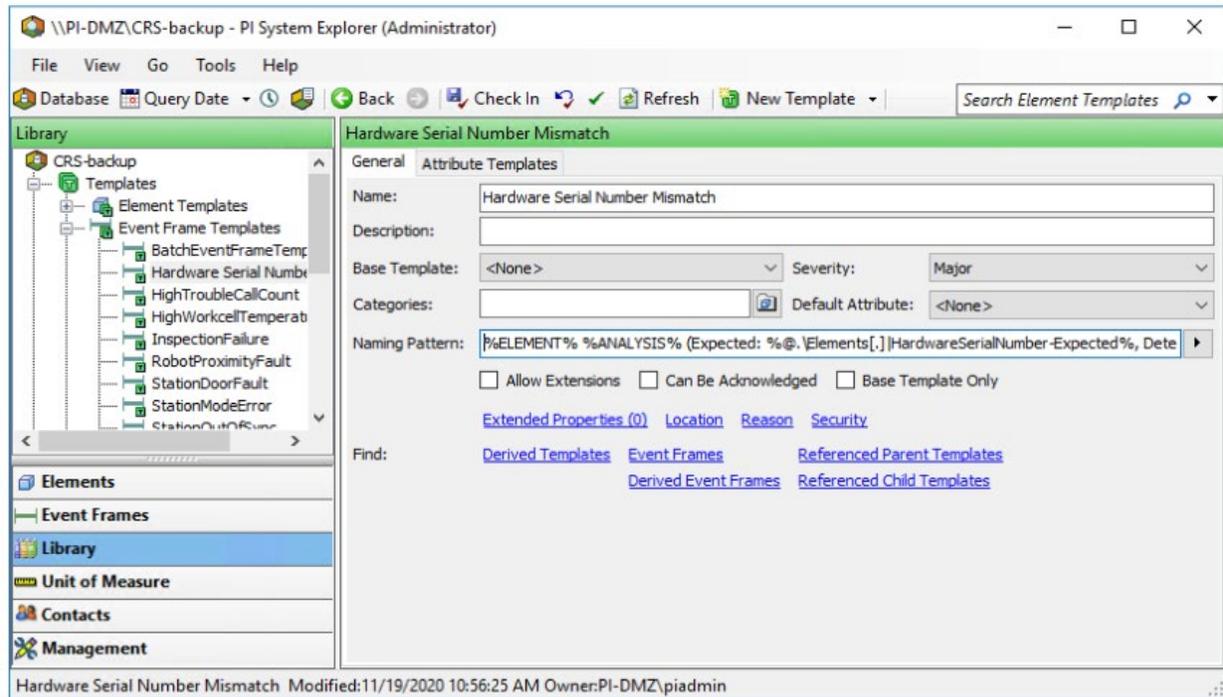
1423 b. Naming pattern: %ELEMENT% %ANALYSIS% (Expected:

1424 %@.\Elements[.]|HardwareSerialNumber-Expected%, Detected:

1425 %@.\Elements[.]|HardwareSerialNumber%) %STARTTIME:yyyy-MM-

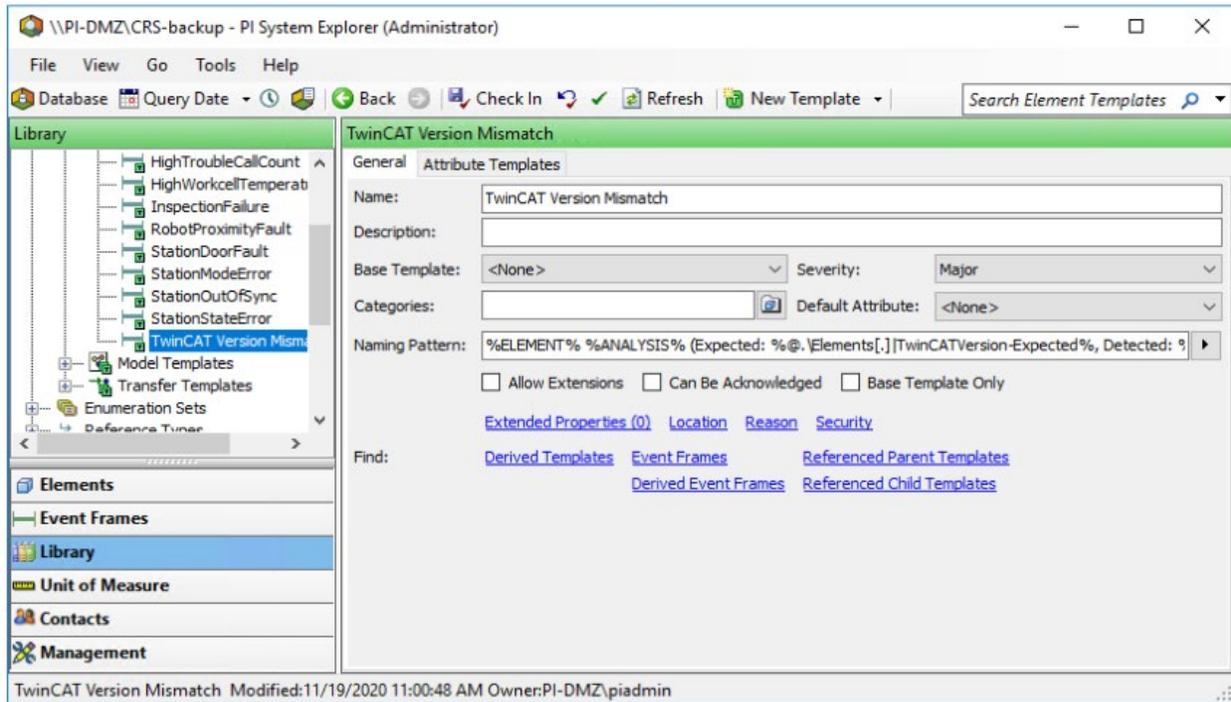
1426 dd HH:mm:ss.fff%

1427 Figure 2-35 Screenshot of PI System Explorer Displaying the Hardware Serial Number Mismatch Event
 1428 Frame Template.



- 1429
- 1430 3. On the top menu bar click **New Template** and enter the following configuration as shown in
 1431 Figure 2-36:
- 1432 a. Name: TwinCAT Version Mismatch
- 1433 b. Naming pattern: %ELEMENT% %ANALYSIS% (Expected:
 1434 %@.\Elements[.]|TwinCATVersion-Expected%, Detected:
 1435 %@.\Elements[.]|TwinCATVersion%) %STARTTIME:yyyy-MM-dd
 1436 HH:mm:ss.fff%

1437 Figure 2-36 Screenshot of PI System Explorer Displaying the TwinCAT Version Mismatch Event Frame
 1438 Template



1439

1440

1441

4. Click the **Check In** button on the top menu to save all changes to the database.

1442

5. In the navigation tree in the **Library** panel, select **Templates > Element Templates > PLCTemplate**.

1443

1444

6. Open the **Analysis Templates** tab in the **PLCTemplate** panel and click **Create a new analysis template**.

1445

1446

7. Enter the following configuration as shown in Figure 2-37:

1447

- a. Name: Hardware Serial Number Mismatch

1448

- b. Description: The PLC hardware serial number does not match the expected serial number.

1449

1450

- c. Analysis Type: Event Frame Generation

1451

- d. Enable analyses when created from template: Checked

1452

- e. Generation Mode: Explicit Trigger

1453

- f. Event Frame Template: Hardware Serial Number Mismatch

1454

8. In the **Expression** field for “StartTrigger1”, enter the expression:

DRAFT

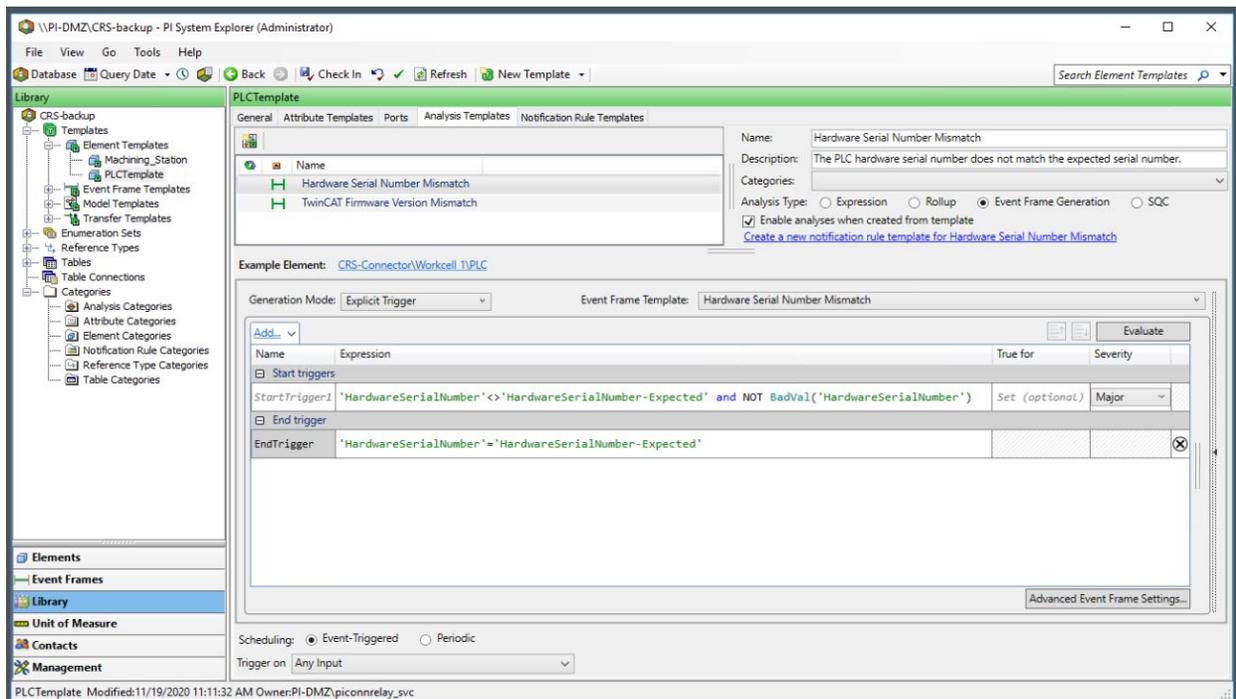
1455 'HardwareSerialNumber' <> 'HardwareSerialNumber-Expected' and NOT
1456 BadVal('HardwareSerialNumber');

1457 9. Click **Add...** drop-down menu and select End Trigger, and enter the expression:

1458 'HardwareSerialNumber'='HardwareSerialNumber-Expected';

1459 10. Select the “Event-Triggered” option for the **Scheduling** type and “Any Input” for the **Trigger On**
1460 drop-down menu.

1461 **Figure 2-37 Screenshot of PI System Explorer Displaying the Hardware Serial Number Mismatch**
1462 **Analysis Template in the PLC Element Template**



1463

1464

1465 11. To create a new analysis template for TwinCAT firmware version mismatch, click **Create a new**
1466 **analysis template.**

1467 12. Enter the following configuration as shown in Figure 2-38:

1468 a. Name: TwinCAT Firmware Version Mismatch

1469 b. Description: The TwinCAT version installed in the PLC does not
1470 match the expected version.

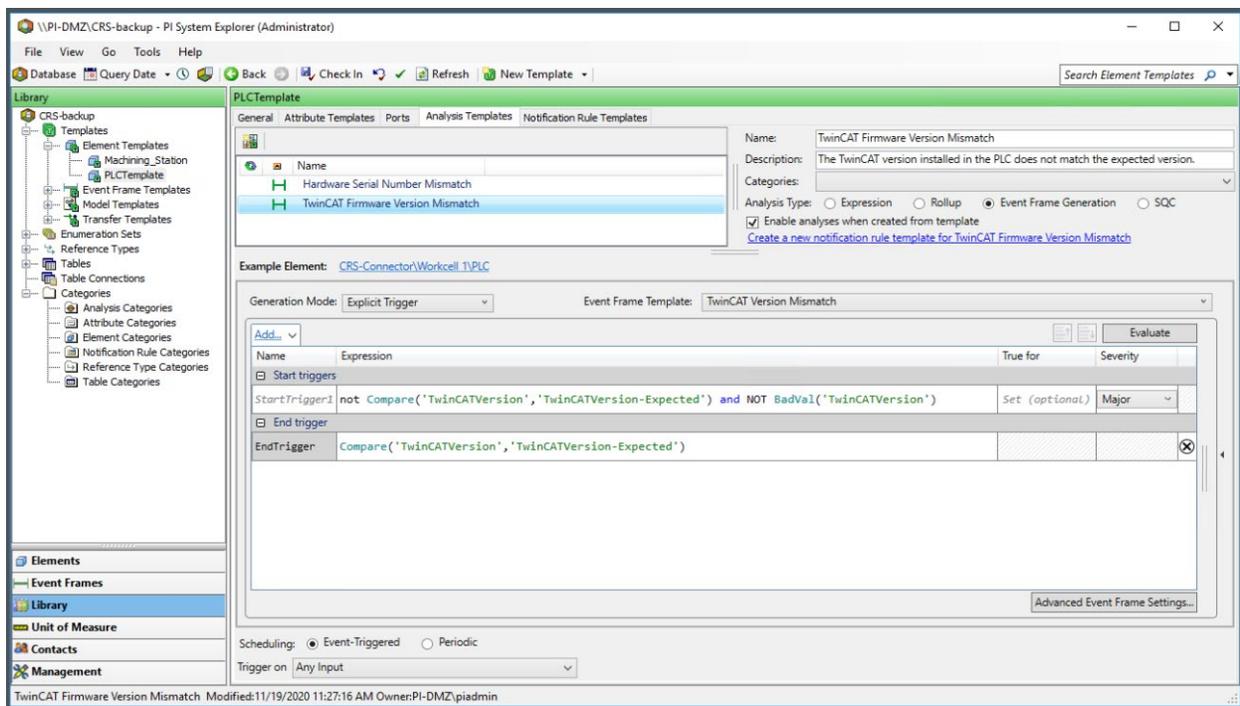
1471 c. Analysis Type: Event Frame Generation

1472 d. Enable analyses when created from template: Checked

1473 e. Generation Mode: Explicit Trigger

- 1474 f. Event Frame Template: Hardware Serial Number Mismatch
- 1475 13. In the **Expression** field for “StartTrigger1”, enter the expression:
- 1476 `not Compare('TwinCATVersion', 'TwinCATVersion-Expected') and NOT`
 1477 `BadVal('TwinCATVersion');`
- 1478 14. Click the **Add...** drop-down menu and select **End Trigger**, and enter the expression:
- 1479 `Compare('TwinCATVersion', 'TwinCATVersion-Expected');`
- 1480 15. Select the “Event-Triggered” option for the **Scheduling** type and “Any Input” from the **Trigger**
 1481 **On** drop-down menu.

1482 **Figure 2-38 Screenshot of PI System Explorer Displaying the TwinCAT Firmware Version Mismatch**
 1483 **Analysis Template in the PLC Element Template**



- 1484
- 1485
- 1486 16. On the top menu bar click **Check In**, verify the changes in the dialog box and click the **Check In**
 1487 **button**.
- 1488 17. On the left navigation panel, select **Elements**.
- 1489 18. In the navigation tree in the **Elements** panel, select **CRS-Connector > Workcell 1 > PLC**.
- 1490 19. Open the **Attributes** tab in the PLC panel.
- 1491 20. Select the attribute **HardwareSerialNumber-Expected** and enter the expected hardware serial
 1492 **number** (e.g., 5870) in the **Value** textbox.

1493 21. Select the attribute **TwinCATVersion-Expected** and enter the expected hardware serial number
1494 (e.g., 3.1.4022) in the **Value** textbox.

1495 22. On the top menu bar and click **Check In**, verify the changes in the dialog box, and click **Check In**.

1496 Event frames will now be generated in the DMZ Historian if the PLC reports a hardware serial number
1497 that does not match the expected value or if the TwinCAT firmware version number does not match the
1498 expected value.

1499 2.7 Security Onion

1500 Security Onion is a Linux-based, open source security playbook. It includes numerous security tools for
1501 intrusion detection, log management, incident response, and file integrity monitoring. For this project,
1502 the tool Wazuh was used in Builds 2 and 4 for file integrity checking. Wazuh works at the host-level to
1503 detect unusual and unauthorized activity and changes to file and software configurations. Security
1504 Onion and Wazuh use Elastic Stack components, Elasticsearch, Filebeat, and Kibana to store, search, and
1505 display alert data.

1506 Note: Wazuh is a fork of the open source project OSSEC, a host-based intrusion detection system. In
1507 some places in Wazuh and this document, the term OSSEC will be used in place of Wazuh.

1508 2.7.1 Host and Network Configuration

1509 Wazuh is an agent-based software. For this project, an existing Security Onion server was used, and the
1510 Wazuh agent was installed on multiple endpoints in both the PCS and CRS environments. The tables
1511 below list the network configuration for the Security Onion server (Table 2-13) and the hosts (Table 2-14
1512 and Table 2-15) with the installed agent.

1513 **Table 2-13 Security Onion Domain Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
Security On- ion Server	Hyper-V VM	Ubuntu 16.04 LTS	4	16GB	450GB	Testbed LAN 10.100.0.26
Nessus VM	Hyper-V VM	Windows 2012R2	2	6GB	65GB	Testbed LAN 10.100.0.25
Dispel VDI	Hyper-V VM	Windows 2016	2	8GB	126GB	DMZ LAN 10.100.1.61
DMZ Histo- rian	Hyper-V VM	Windows 2016	4	8GB	80GB/171GB	DMZ LAN 10.100.1.4

1514

1515 **Table 2-14 Security Onion PCS Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
PCS Engineering Workstation	HP Z230 Tower PC	Windows 7	4	16GB	465GB	PCS LAN 3 172.16.3.10
PCS HMI Host	Supermicro Z97X-Ud5H	Windows 7	4	8GB	600GB	PCS LAN 1 172.16.1.4

1516

1517 **Table 2-15 Security Onion CRS Hosts Deployment**

Name	System	OS	CPU	Memory	Storage	Network
CRS Engineering Workstation	Dell Precision T5610	Windows 10	8	16GB	465GB	CRS Supervisory 192.168.0.20

1518

1519

2.7.2 Installation

1520 Security Onion Server version 3.9 and Wazuh Agent version 3.9 were used.

1521 Installation of Wazuh involves setting up the central server and installing agents on hosts that needed to
1522 be monitored.1523 Security Onion server contains the Wazuh manager and API components as well as the Elastic Stack. The
1524 Wazuh manager is responsible for collecting and analyzing data from deployed agents. The Elastic Stack
1525 is used for reading, parsing, indexing, and storing alert data generated by the Wazuh manager.1526 The Wazuh agent, which runs on the monitored host, is responsible for collecting system log and
1527 configuration data and detecting intrusions and anomalies. The collected data is then forwarded to the
1528 Wazuh manager for further analysis.1529 The Security Onion server was already a part of the lab infrastructure prior to this effort. For the server
1530 component installation process, please follow the guidance from the Security Onion Installation Guide
1531 for version 3.9 available at <https://documentation.wazuh.com/3.9/installation-guide/index.html>.1532 For information on adding agents to the server, please follow the guidance from the Security Onion
1533 Installation Guide for version 3.9 available at [https://documentation.wazuh.com/3.9/user-
1534 manual/registering/index.html](https://documentation.wazuh.com/3.9/user-manual/registering/index.html).1535

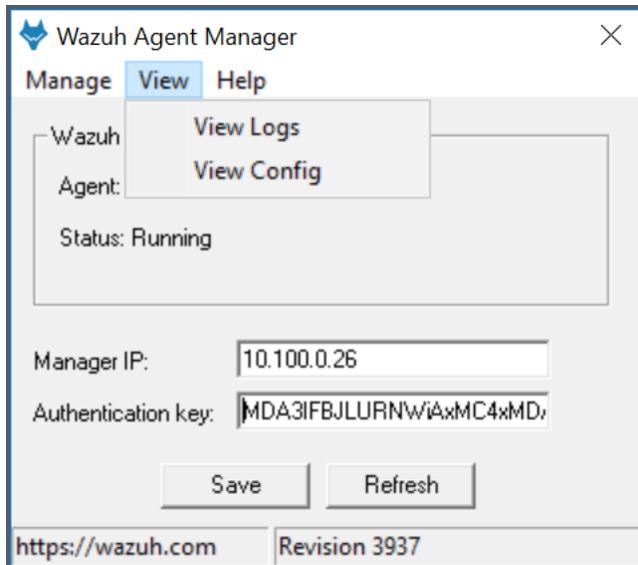
2.7.3 Configuration

1536 1. Configure Additional Directories or Files for Wazuh Agent File Integrity Monitoring:

1537 a. Files and directories to be monitored are specified in the ossec.conf file on each host.

- 1538 i. To view or edit this file, click the View tab in the Wazuh Configuration Manager
 1539 on the host machine and select View Config as shown in Figure 2-39.

1540 **Figure 2-39 Wazuh Agent Manager**



- 1541
 1542 b. Selecting View Config opens the ossec.conf file in Notepad. Alternatively, the file can be
 1543 opened in Notepad from its location in the "C:\Program Files (x86)\ossec-agent" direc-
 1544 tory on the host machine, as shown in Figure 2-40.

1545 **Figure 2-40 ossec.conf File**

```

<!-- Directories added for NCCOE Project -->
<directories check_all="yes" whodata="yes">C:\testscenarios</directories>
<directories check_all="yes" whodata="yes">C:\EngWorkstation_Share</directories>
<directories check_all="yes" whodata="yes">C:\Program Files (x86)\ControlFLASH</directories>
<directories check_all="yes" whodata="yes">C:\Users\Administrator\Documents</directories>
<directories check_all="yes" whodata="yes">C:\Users\Administrator\Downloads</directories>

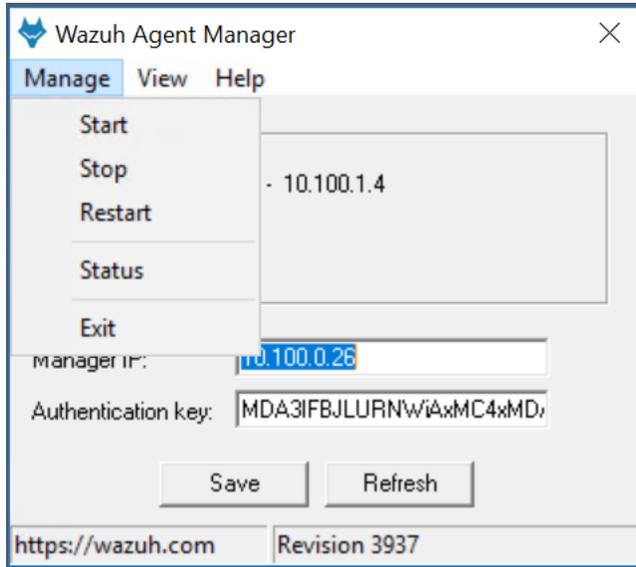
<ignore>%PROGRAMDATA%\Microsoft\Windows\Start Menu\Programs\Startup\desktop.ini</ignore>

<ignore type="sregex">.log$|.htm$|.jpg$|.png$|.chm$|.pnf$|.evt$</ignore>
  
```

- 1546
 1547 c. To add files or directories to the default configuration, copy and modify an existing line
 1548 in the ossec.conf file to ensure the proper XML syntax is used.

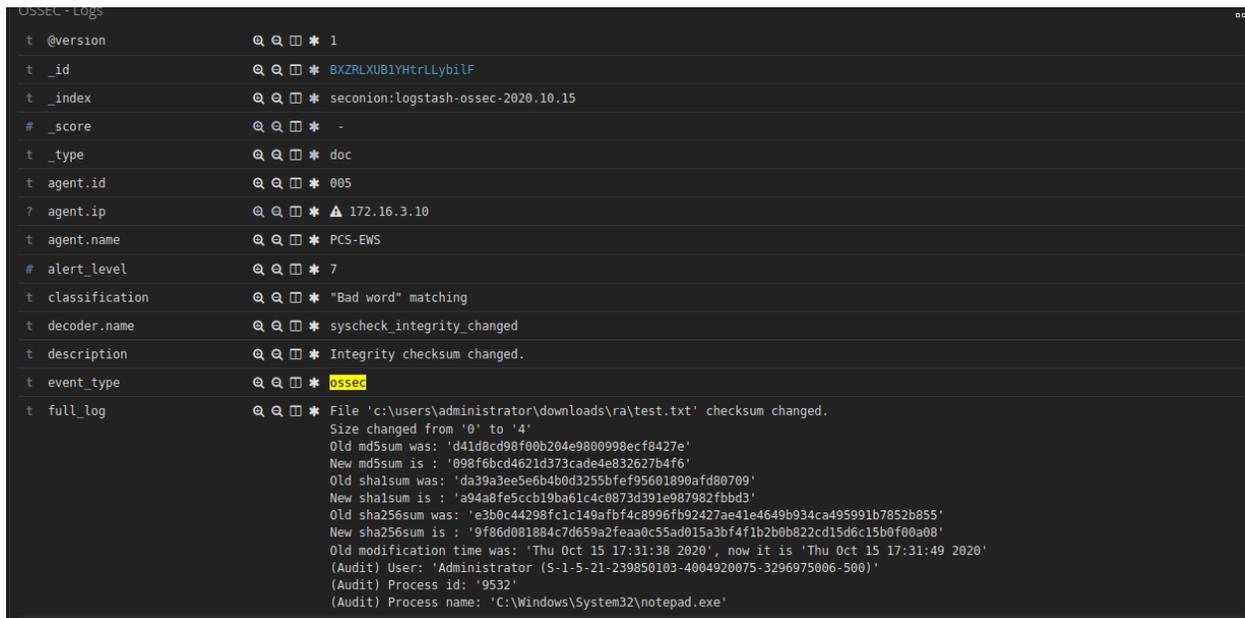
- 1549 d. Once the changes are made, save the ossec.conf file and restart the Wazuh Agent by
- 1550 opening the Configuration Manager, selecting "Manage", and "Restart" as shown in Fig-
- 1551 ure 2-41.

1552 **Figure 2-41 Wazuh Agent Manager User Interface**



- 1553
- 1554 e. Changes to the files or directories specified in the ossec.conf file will be detected and
- 1555 sent to the Wazuh Manager. Figure 2-42 shows the log received after a file change was
- 1556 detected.

1557 **Figure 2-42 Log Received After a File Change Was Detected**



- 1558

1559 2.8 TDi ConsoleWorks

1560 The TDi ConsoleWorks implementation in Builds 1 and 3 consists of a single VM hosted on VMWare ESXi
 1561 to meet the user authentication and authorization capabilities. ConsoleWorks provides a secure web
 1562 interface through which authenticated and authorized users receive access to graphical and shell
 1563 interfaces on configured ICS components.

1564 2.8.1 Host and Network Configuration

1565 ConsoleWorks resides on a VM that was reconfigured for supporting Builds 1 and 3 as described in Table
 1566 2-16 and Table 2-17 respectively.

1567 Table 2-16 ConsoleWorks Build 1 Deployment

Name	System	OS	CPU	Memory	Storage	Network
ConsoleWorks	VMWare VM	CentOS 7	8x vCPU	8GB	500 GB 750 GB	Testbed LAN 10.100.0.53

1568

1569 Table 2-17 ConsoleWorks Build 3 Deployment

Name	System	OS	CPU	Memory	Storage	Network
ConsoleWorks	VMWare VM	CentOS 7	8x vCPU	8GB	500 GB 750 GB	CRS 192.168.0.65

1570

1571 2.8.2 Installation

1572 ConsoleWorks version 5.3-1u3 is installed on a CentOS 7 operating system using the following
 1573 procedures. Product installation guides and documentation are available at
 1574 <https://support.tditechnologies.com/product-documentation>. Follow these steps for installation:

1575 1. Harden and configure the Operating System:

1576 a. Log in to the system with privileged access and set the Static IP Address information by
 1577 editing `/etc/sysconfig/network-scripts/ifcfg-eth0` using the following settings:

1578 i. For Build 1 use the following network configuration:

1579 1) IP Address: **10.100.0.53**

1580 2) Subnet Mask: **255.255.255.0**

1581 3) Gateway: **10.100.0.1**

1582 4) DNS: **10.100.0.17**

1583 ii. For Build 3 use the following network configuration:

1584 1) IP Address: **192.168.0.65**

- 1585 2) Subnet Mask: **255.255.255.0**
- 1586 3) Gateway: **192.168.0.2**
- 1587 4) DNS: **10.100.0.17**
- 1588 iii. Restart the network service as follows:
- 1589 **# systemctl restart network**
- 1590 b. Set the NTP Configuration as follows:
- 1591 i. In */etc/ntp.conf*, add as the first server entry:
- 1592 **server 10.100.0.15**
- 1593 c. Apply the following Department of Defense (DOD) Security Technology Implementation
- 1594 Guide (STIG) settings:
- 1595 i. Ensure ypserv is not installed using the following command:
- 1596 **# yum remove ypserv**
- 1597 ii. Ensure Trivial File Transfer Protocol (TFTP) is not installed using the following
- 1598 command:
- 1599 **# yum remove tftp-server**
- 1600 iii. Ensure RSH-SERVER is not installed using the following command:
- 1601 **# yum remove rsh-server**
- 1602 iv. Ensure File Transfer Protocol (FTP) is not installed using the following command:
- 1603 **# yum remove vsftpd**
- 1604 v. Ensure TELNET-SERVER is not installed using the following command:
- 1605 **# yum remove telnet-server**
- 1606 vi. Configure SSH to use SSHv2 only.
- 1607 1) To disable SSHv1, ensure only Protocol 2 is allowed in the
- 1608 */etc/ssh/sshd_config*.
- 1609 **Protocol 2**
- 1610 **PermitRootLogin no**
- 1611 **Ciphers aes128-ctr, aes192-ctr, aes256-ctr, aes128-**
- 1612 **cbc**
- 1613 **MACs hmac-sha2**
- 1614 vii. Disallow authentication using an empty password as follows:
- 1615 1) Add **PermitEmptyPasswords no** to */etc/ssh/sshd_config* file.

- 1616 2) Remove any instances of the **nullok** option in `/etc/pam.d/system-auth` and
1617 `/etc/pam.d/password-auth` files.
- 1618 viii. Enable FIPS Mode as follows:
- 1619 1) FIPS mode can be enabled by running the command:
- 1620 `# yum install dracut`
1621 `# dracut -f`
- 1622 2) When step 1) is complete, add **fips=1** to the `/etc/default/grub` file and run
1623 the command:
- 1624 `# grub2-mkconfig -o /boot/efi/EFI/redhat/grub.cfg`
- 1625 3) When step 2) completes, reboot the server with this command:
- 1626 `# reboot`
- 1627 ix. Enable server auditing
- 1628 1) Ensure events on the server are being recorded for investigation in the
1629 event of an outage or attack. This can be enabled by running the command:
- 1630 `# systemctl start auditd.service.`
- 1631 x. Configure system to only install approved digitally signed packages:
- 1632 1) Configure yum to verify the Certificate Authority is from an approved
1633 organization. To enable this, ensure that **gpgcheck=1** is in the
1634 `/etc/yum.conf` file.
- 1635 xi. Enable the firewall:
- 1636 1) To enable the firewall, run the following commands:
- 1637 `# yum install firewalld and`
1638 `# systemctl start firewalld.`
- 1639 2) Check Firewall Zone and confirm only SSH and HTTPS is allowed. Note: the
1640 default zone is Public and SSH is already permitted. For the
1641 implementation, we checked the configuration using the following
1642 command:
- 1643 `# firewall-cmd --list-all`
- 1644 3) Add the HTTPS configuration to the firewall using the following command:
- 1645 `# firewall-cmd --zone=public --permanent --add-`
1646 `service=https`
- 1647 xii. Enable SELinux and set to "targeted":

1648 1) Add SELINUX=enforcing and SELINUXTYPE=targeted in the
1649 /etc/selinux/config file and then reboot the server with this command:

```
1650 # reboot
```

1651 xiii. Enable Antivirus as follows:

1652 1) ClamAV is used for the lab implementation using the following commands
1653 adapted from information found on
1654 <https://www.clamav.net/documents/clam-antivirus-user-manual>:

```
1655 # yum install -y epel-release
1656 # yum -y install clamav-server clamav-data
1657 clamav-update clamav-filessystem clamav clamav-
1658 scanner-systemd clamav-devel clamav-lib clamav-
1659 server-systemd
```

1660 2) Update SELinux policy to allow ClamAV to function

```
1661 # setsebool -P antivirus_can_scan_system 1
```

1662 3) Make a backup copy of the scan.conf file and update to remove the
1663 Example string from the file using these commands:

```
1664 # cp /etc/clamd.d/scan.conf /etc/clamd.d/scan.conf.bk
1665 # sed -i '/^Example/d' /etc/clamd.d/scan.conf
```

1666 4) Uncomment the following line from /etc/clamd.d/scan.conf:

```
1667 LocalSocket /var/run/clamd.scan/clamd.sock
```

1668 5) Configure freshclam to automatically download updated virus definitions
1669 using these commands:

```
1670 # cp /etc/freshclam.conf /etc/freshclam.conf.bak
1671 # sed -i -e "s/^Example/#Example/" /etc/freshclam.conf
```

1672 6) Manually run freshclam to confirm the settings as follows:

```
1673 # freshclam
```

1674 7) Start and enable the clamd service with these commands:

```
1675 # systemctl start clamd@scan
1676 # systemctl enable clamd@scan
```

1677 8) Ensure log directory is available with this command:

```
1678 # mkdir /var/log/clamav
```

1679 9) Create the daily scan script to scan directories of interest. Note: for the lab
1680 implementation only the /home volume was selected for scanning.

1681 `# vi /etc/cron.daily/clamav_scan.sh`

1682

1683 **File Contents**

1684

1685 `#!/bin/bash`

1686 `SCAN_DIR="/home"`

1687 `LOG_FILE="/var/log/clamav/dailyscan.log"`

1688 `/usr/bin/clamscan -ri $SCAN_DIR >> $LOG_FILE`

1689 10) Set the file to have execute privilege with this command:

1690 `# chmod +x /etc/cron.daily/clamav_scan.sh`

1691 2. Download and Install the ConsoleWorks packages

1692 a. Login to TDi Technology Support Portal (https://support.tditechnologies.com/get_consoleworks) to download the ConsoleWorks for Linux 5.3-1u3 installation package. Cre-
1693 dentials will be provided by TDi.
1694

1695 b. After downloading the ConsoleWorks installation package, copy it to the ConsoleWorks
1696 VM using a Secure Copy (scp) utility.

1697 c. Follow the procedures from TDi ConsolWorks New Installation and Upgrade Guide for
1698 Linux Chapter 3: Automated New Installation of ConsoleWorks

1699 i. During installation, create a New Invocation named "NCCOE".

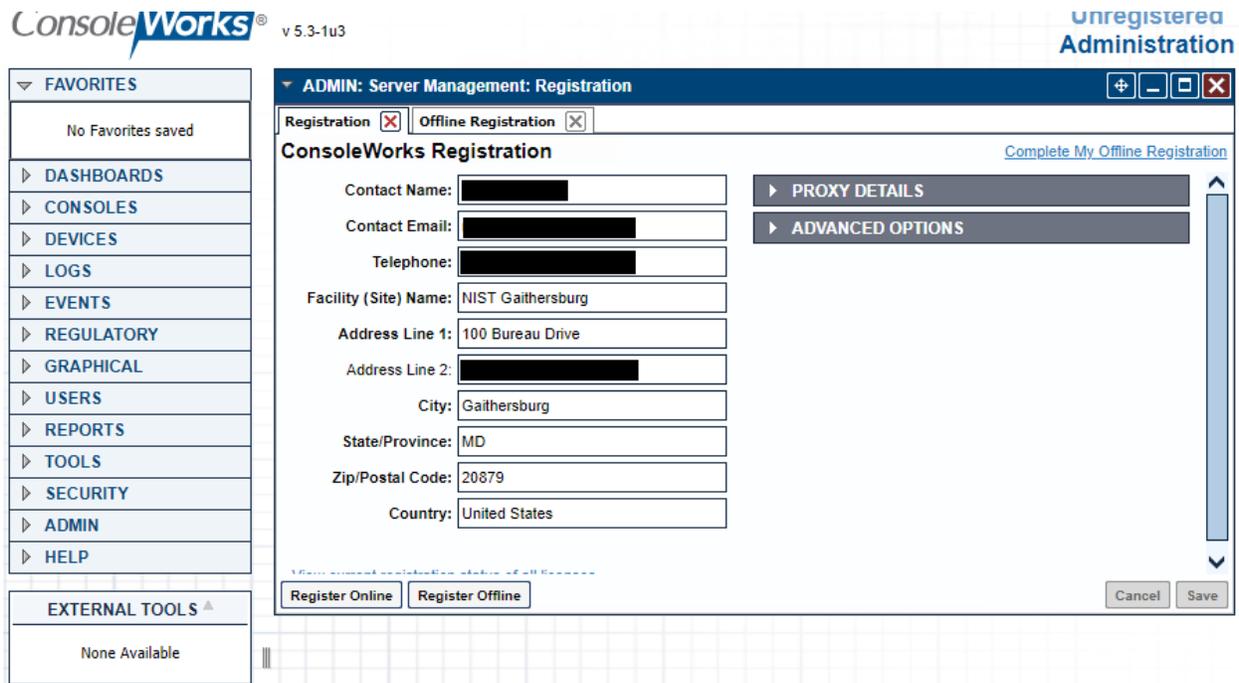
1700 ii. Create a new certificate.

1701 iii. Set the system to automatically start the ConsoleWorks Invocation.

1702 d. Login to the platform and initiate the offline registration process (Figure 2-43).

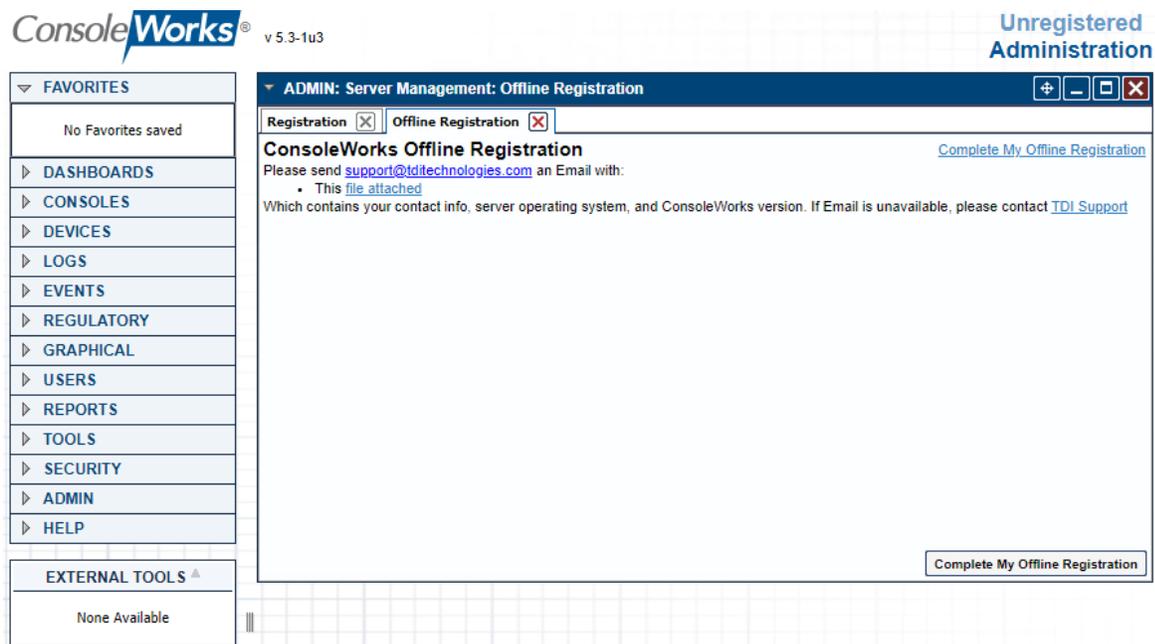
1703 e. Once the license file is obtained, complete the registration process (Figure 2-44).

1704 Figure 2-43 ConsoleWorks Registration Screen



1705

1706 Figure 2-44 ConsoleWorks Offline Registration Process



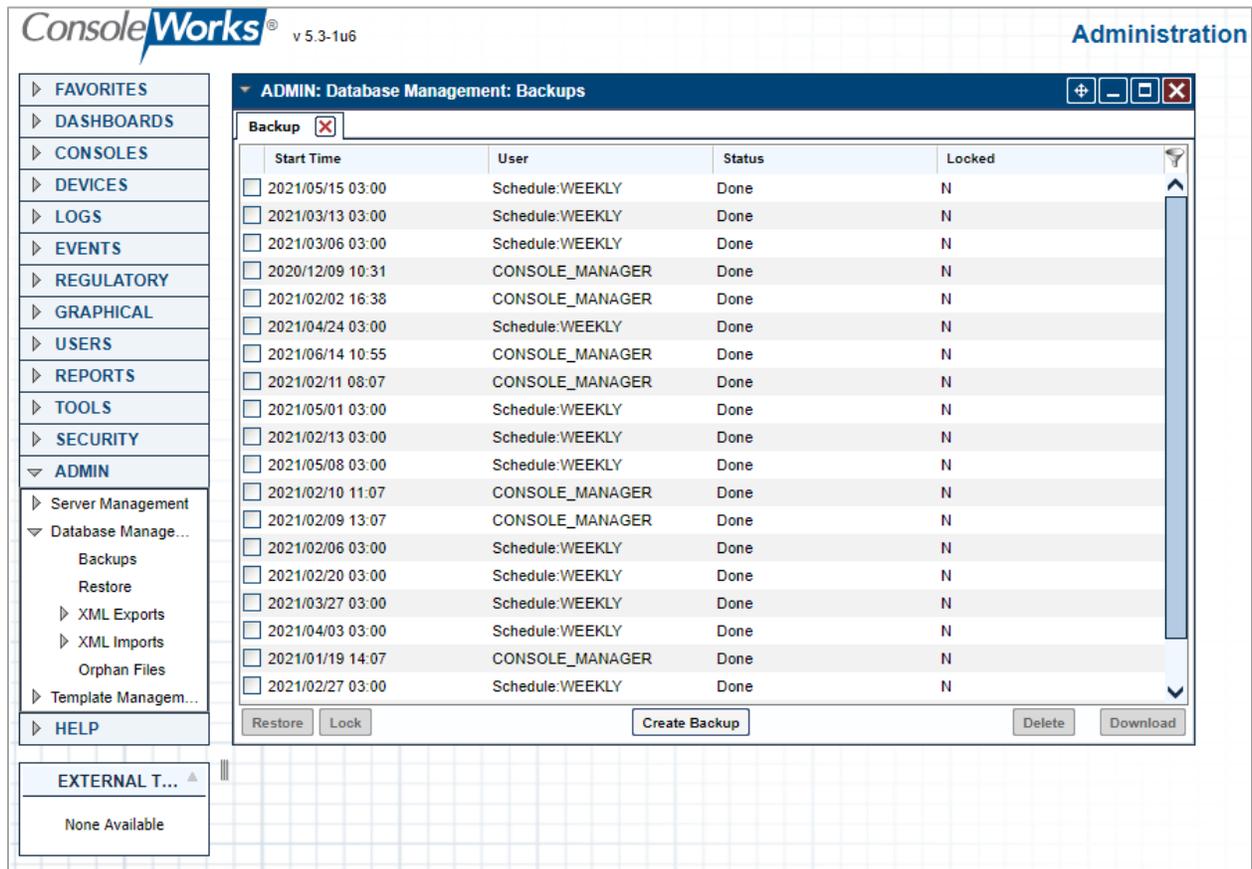
1707

- 1708 f. This completes the default installation and establishes a basic ConsoleWorks server con-
 1709 figuration. For the lab implementation, ConsoleWorks support provided two additional
 1710 add-on packages (XML) files to setup the environment: ONBOARDING_1-DASH-
 1711 BOARDS_NCCoE.zip providing preconfigured dashboards for accelerating configurations;
 1712 and NCCOE_ACRs_20210122_083645.zip providing the access control rules, tags, and

1713 automation scripts used for the dashboards. These packages are scheduled for inclusion
 1714 in future releases or can be requested from ConsoleWorks.

1715 i. Prior to installing these packages, a backup of the configuration should be made
 1716 (Figure 2-45) by accessing **Admin > Database Management > Backups** and click-
 1717 ing **Create Backup**.

1718 **Figure 2-45 ConsoleWorks System Backups**



1719

1720 ii. Perform the XML Imports (Figure 2-46) by accessing **Admin > Database Manage-**
 1721 **ment > XML Imports** following these steps:

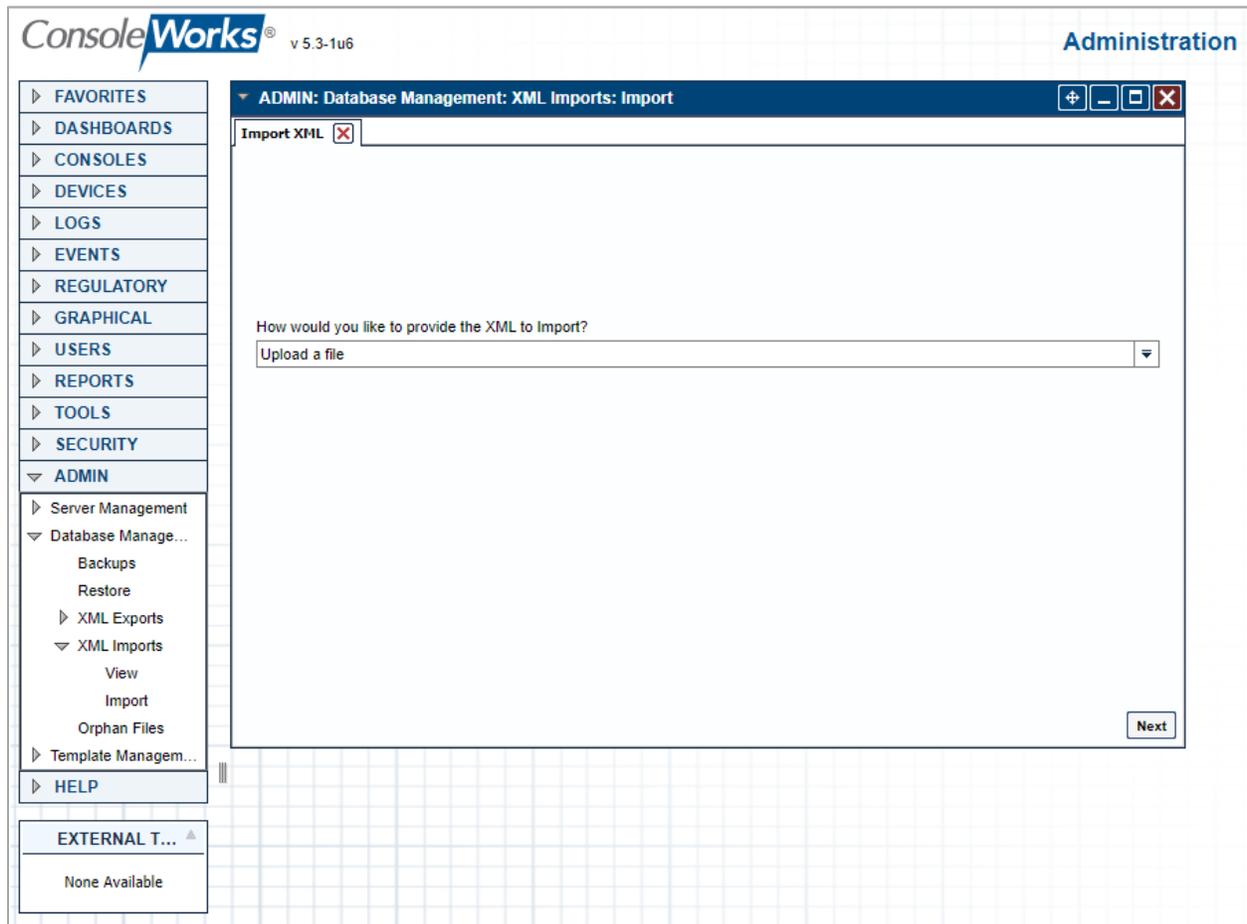
1722

1) Import the *Dashboard Add-On XML* file.

1723

2) Import the *Supporting Configuration Add-On XML* file.

1724 Figure 2-46 ConsoleWorks Importing System Configurations and Components



1725

1726

2.8.3 Configuration

1727 The ConsoleWorks implementation required the following changes to the lab Cisco VPN appliance to
 1728 allow remote users to access the ConsoleWorks system:

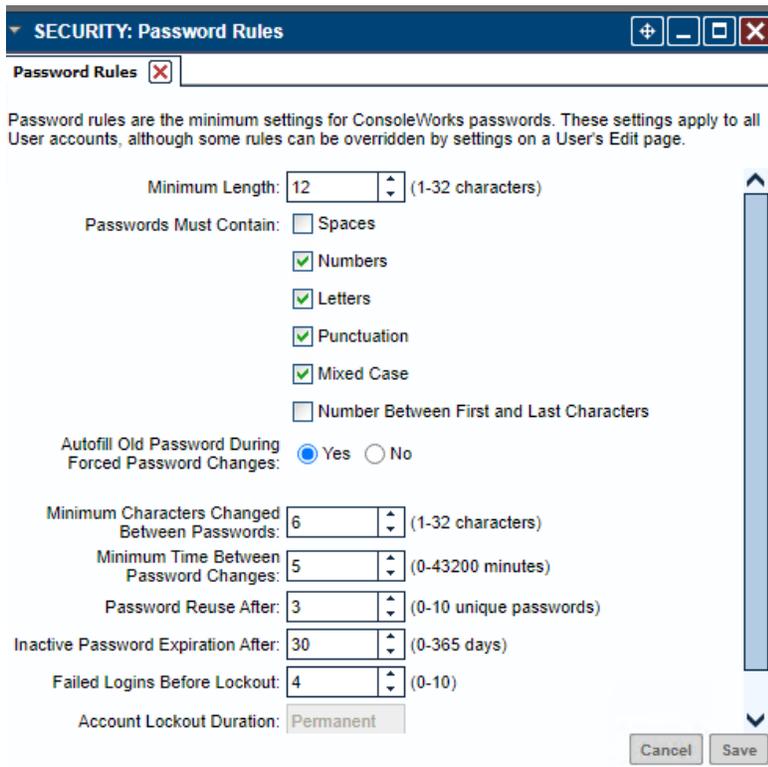
- 1729 1. Login to the Cisco Firepower Appliance.
- 1730 2. Create the Following Destination Network Objects:
 - 1731 a. For Build 1:
 - 1732 i. Name: ConsoleWorks
 - 1733 ii. IP Address: 10.100.0.52
 - 1734 b. For Build 3:
 - 1735 i. Name: CRS-NAT-IP
 - 1736 ii. IP Address: 10.100.0.20
- 1737 3. Create the Following VPN-Rule:

- 1738 a. For Build 1:
- 1739 i. Action: Allow
- 1740 ii. Source Networks: VPN-Pool
- 1741 iii. Destination Networks: ConsoleWorks
- 1742 iv. Destination Ports: TCP (6): 5176; HTTPS
- 1743 b. For Build 3:
- 1744 i. Action: Allow
- 1745 ii. Source Networks: VPN-Pool
- 1746 iii. Destination Networks: CRS-NAT-IP
- 1747 iv. Destination Ports: TCP (6): 5176; HTTPS

1748 ConsoleWorks is then configured as follows. For configuration procedures, please see the ConsoleWorks
1749 documentation available at <https://support.tditechnologies.com/product-documentation>.

- 1750 1. Configure ConsoleWorks Password Rules (Figure 2-47):

1751 **Figure 2-47 ConsoleWorks Password Settings**

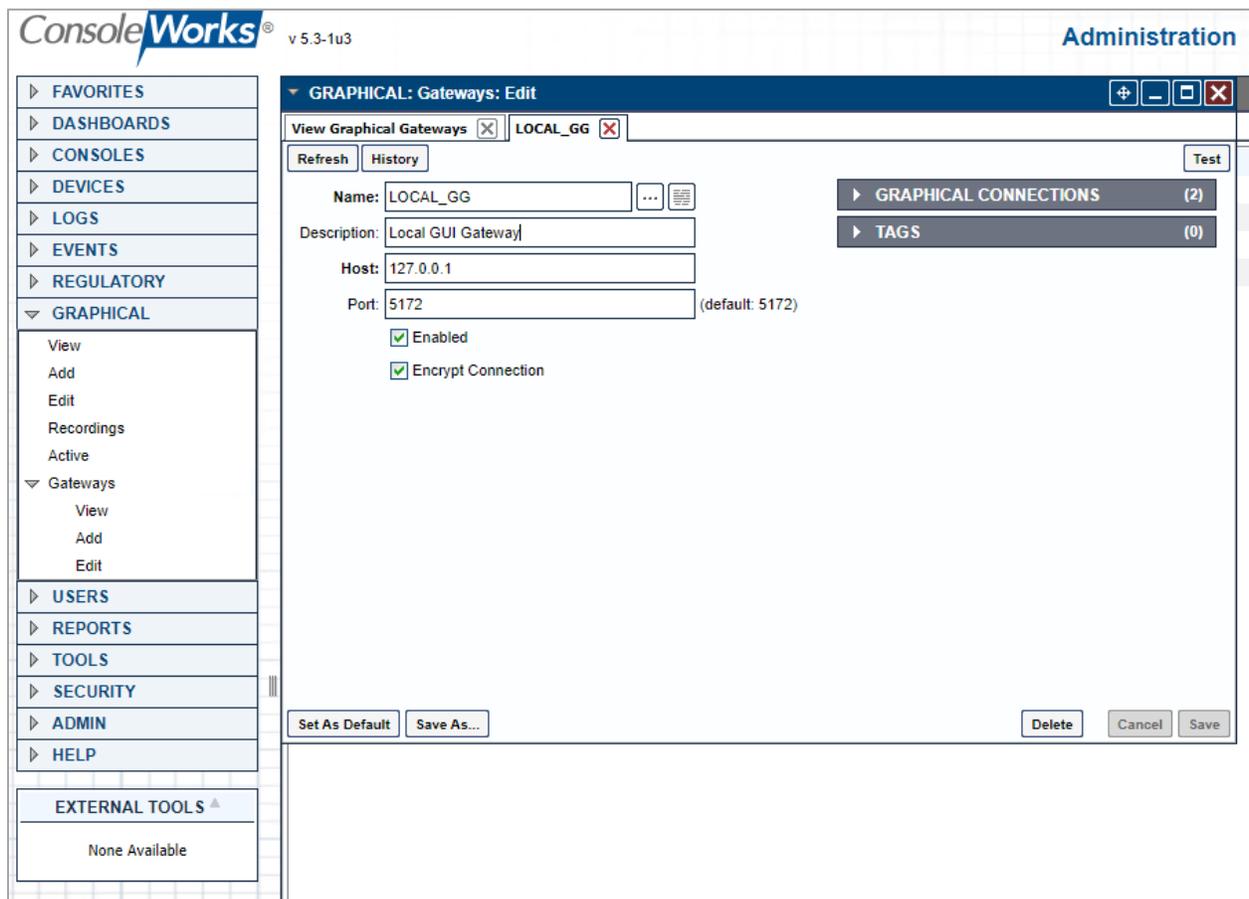


- 1752
- 1753 2. Add user accounts:

- 1754 a. **NCCOE_ADMIN**

- 1755 b. **NCCOE_USER**
- 1756 3. Configure the Graphical Gateway to allow users to use RDP within ConsoleWorks following
- 1757 these steps (Figure 2-48):
- 1758 a. Name: **LOCAL_GG**
- 1759 b. Description: **Local GUI Gateway**
- 1760 c. Host: **127.0.0.1**
- 1761 d. Port: **5172**
- 1762 e. Enabled: **Selected**
- 1763 f. Encrypt Connection: **Selected**

1764 **Figure 2-48 ConsoleWorks Add the Local Graphical Gateway for RDP Access**

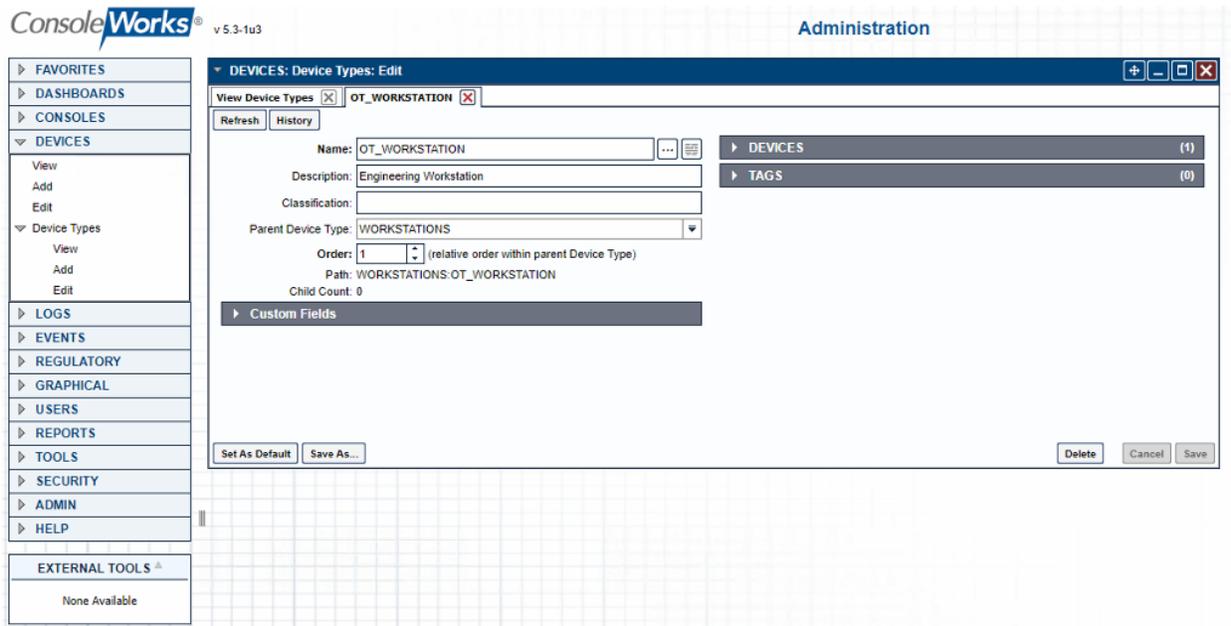


- 1765
- 1766 4. Configure Device Types to organize the registered devices within the system as follows:
- 1767 a. Enter the information for the supported device types as shown in the example device
- 1768 type (Figure 2-49) for each type listed in Table 2-18 (and shown in Figure 2-50).

1769 Table 2-18 ConsoleWorks Device Type List

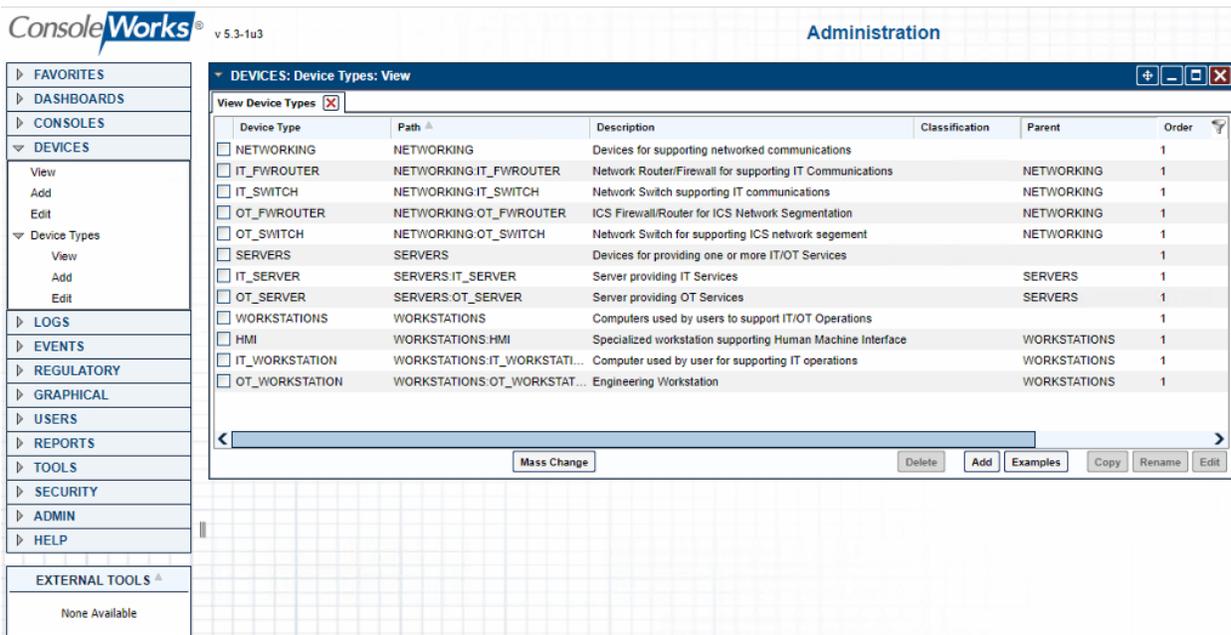
Name	Description	Parent Device Type	Order
NETWORKING	Devices supporting networked communications		1
IT_FWROUTER	Network Router/Firewall for supporting IT Communications	NETWORKING	1
IT_SWITCH	Network switch supporting IT communications	NETWORKING	1
OT_FWROUTER	ICS Firewall/Router for ICS Network Separation	NETWORKING	1
OT_SWITCH	ICS Switch for supporting OT Subnets	NETWORKING	1
SERVERS	Devices for providing one or more IT/OT Services		1
IT_SERVERS	Servers providing IT Services	SERVERS	1
OT_SERVERS	Servers providing OT Services	SERVERS	1
WORKSTATIONS	Computers used to support IT/OT Operations		1
HMI	Specialized workstation supporting human-machine interfaces	WORKSTATIONS	1
IT_WORKSTATIONS	Computers used by users to support IT Operations	WORKSTATIONS	1
OT_WORKSTATIONS	Computers used by users to support OT Operations	WORKSTATIONS	1

1770 Figure 2-49 ConsoleWorks Example Device Type Definition



1771

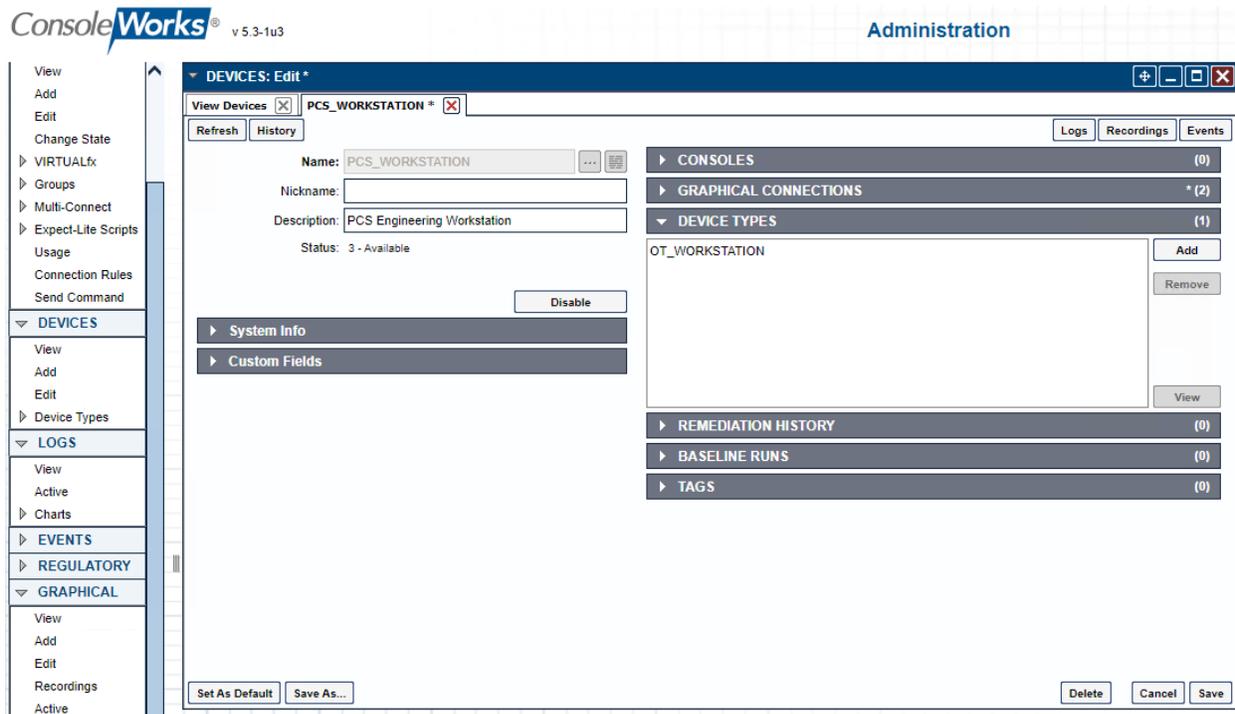
1772 Figure 2-50 ConsoleWorks List of Device Types



1773

1774 5. Configure Devices for each system within the testbed that is accessible from ConsoleWorks.

1775 Figure 2-51 ConsoleWorks Example Device Definition

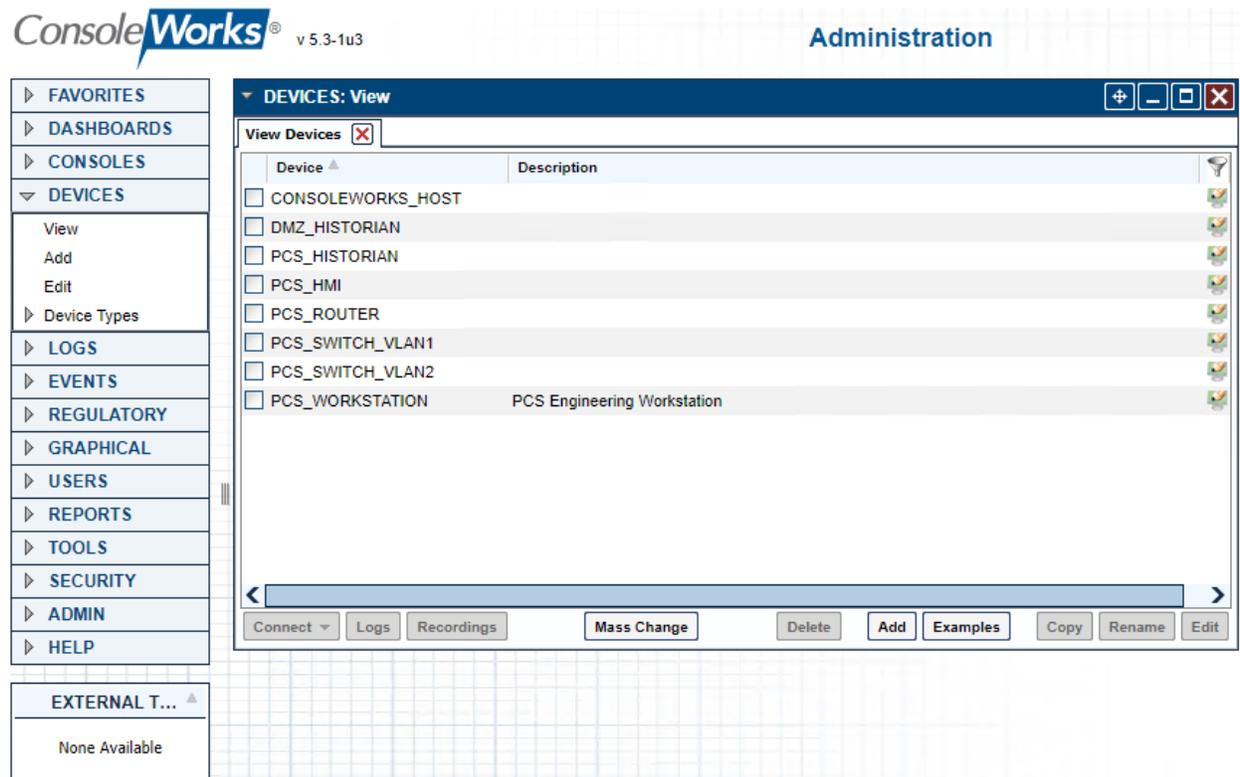


- 1776
- 1777 a. For Build 1 (PCS), enter the information for the devices as shown in the example device
- 1778 (Figure 2-51) for each device listed in Table 2-19 (Figure 2-52).

1779 Table 2-19 ConsoleWorks PCS (Build 1) Devices

Name	Description	Device Type
DMZ_HISTORIAN	Historian in DMZ Subnet	IT_SERVER
PCS_HISTORIAN	Local Historian in PCS Subnet	OT_SERVER
PCS_HMI	PCS HMI Workstation	HMI
PCS_ROUTER	PCS Boundary Firewall/Router	OT_FWROUTER
PCS_SWITCH_VLAN1	PCS VLAN 1 OT Switch	OT_SWITCH
PCS_SWITCH_VLAN2	PCS VLAN 2 OT Switch	OT_SWITCH
PCS_WORKSTATION	PCS Engineering Workstation	OT_WORKSTATIONS

1780 Figure 2-52 ConsoleWorks List of PCS (Build 1) Devices

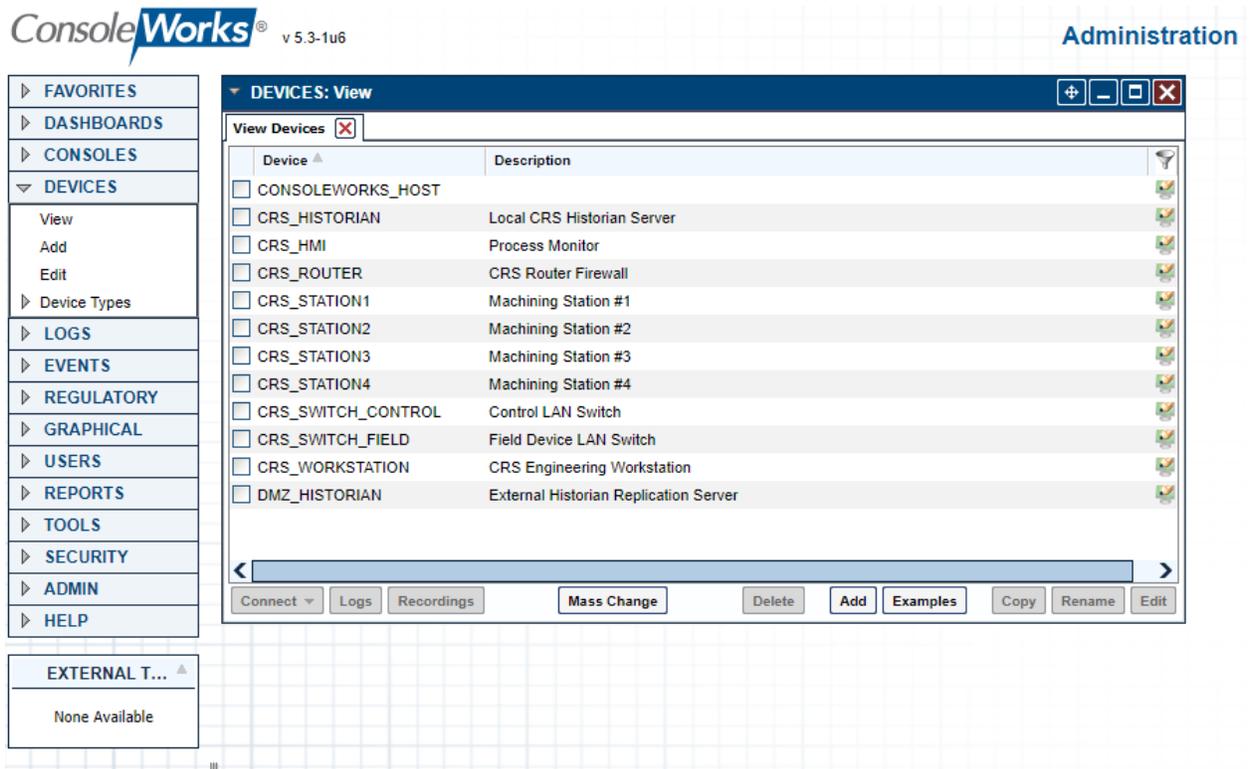


- 1781
- 1782 b. For Build 3 (CRS) , enter the information for the devices as shown in the example device
- 1783 (Figure 2-51) for each device listed in Table 2-20 (also shown in Figure 2-53).

1784 Table 2-20 ConsoleWorks CRS (Build 3) Devices

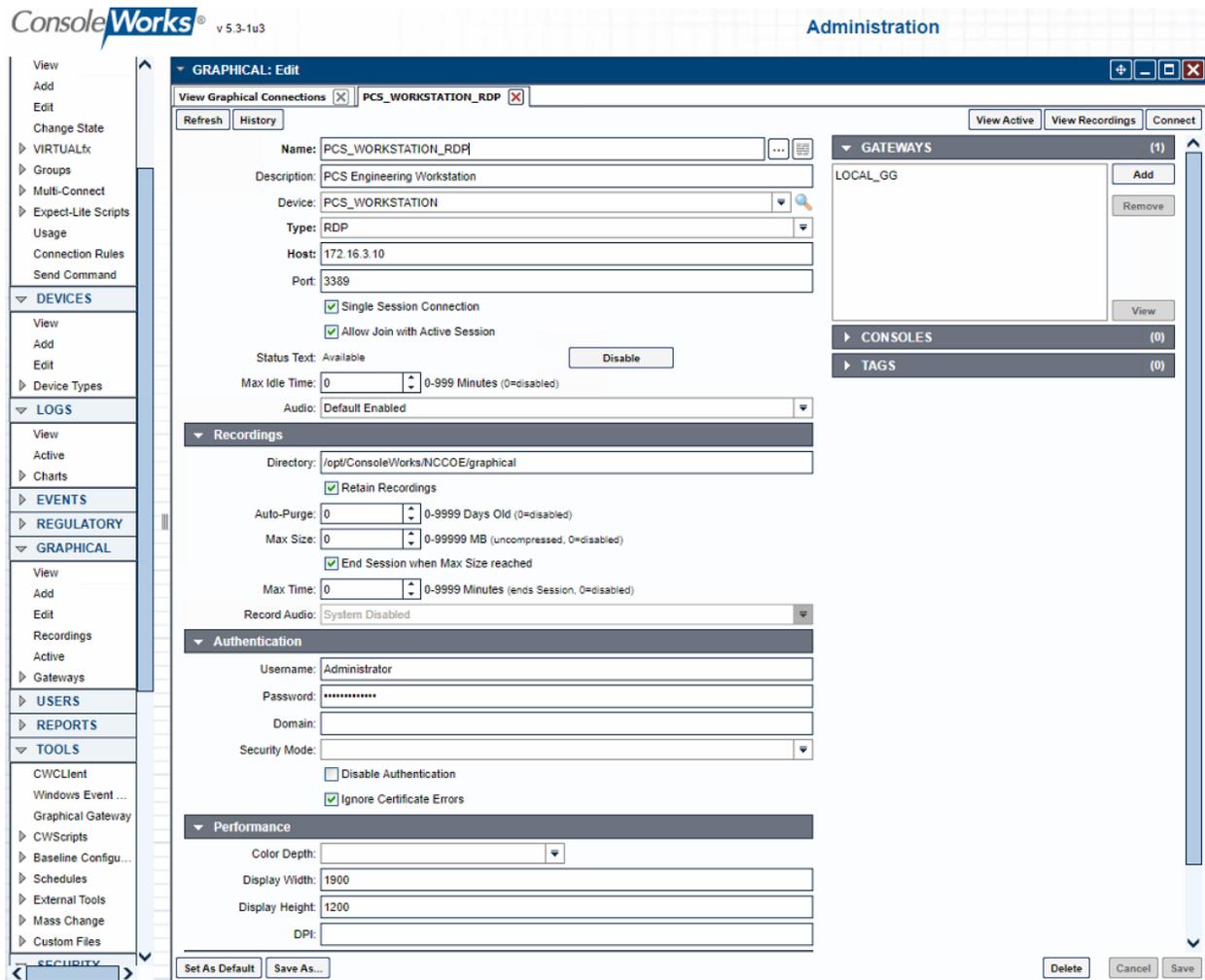
Name	Description	Device Type
DMZ_HISTORIAN	Historian in DMZ Subnet	IT_SERVER
CRS_HISTORIAN	Local Historian in CRS Subnet	OT_SERVER
CRS_HMI	CRS HMI Workstation	HMI
CRS_ROUTER	CRS Boundary Firewall/Router	OT_FWROUTER
CRS_SWITCH_CONTROL	OT Switch for Control Network	OT_SWITCH
CRS_SWITCH_FIELD	OT Switch for Field Network	OT_SWITCH
CRS_WORKSTATION	CRS Engineering Workstation	OT_WORKSTATIONS
CRS_STATION1	Machining Station #1	OT_WORKSTATIONS
CRS_STATION2	Machining Station #2	OT_WORKSTATIONS
CRS_STATION3	Machining Station #3	OT_WORKSTATIONS
CRS_STATION4	Machining Station #4	OT_WORKSTATIONS

1785 Figure 2-53 ConsoleWorks List of CRS (Build 3) Devices



1786 6. Configure Graphical Connections for the PC (RDP) based devices.

1787 Figure 2-54 ConsoleWorks Example RDP Configuration



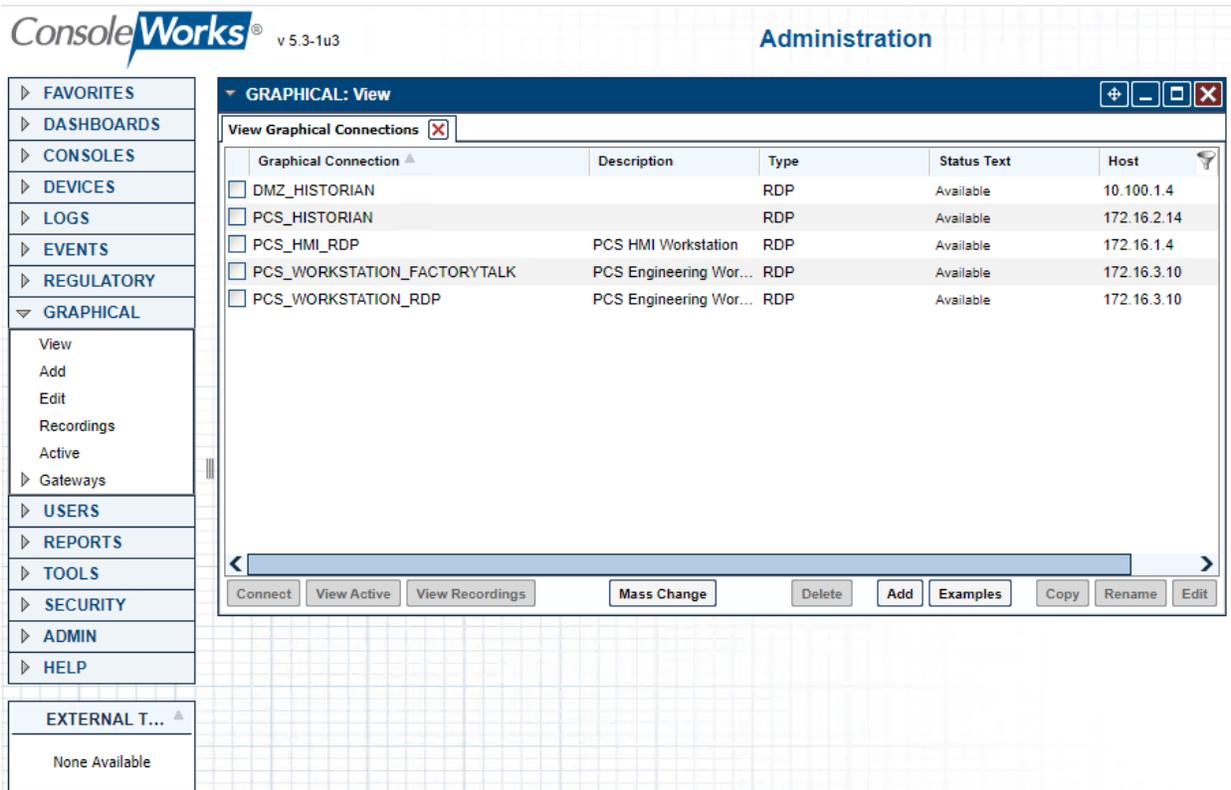
- 1788 a. For Build 1 (PCS), enter the information for the Graphical Connections as shown in the
 1789 example (Figure 2-54) for each graphical connection listed in Table 2-21 (also shown in
 1790 Figure 2-55). For each entry, the following are common settings for all graphical connec-
 1791 tions:
- 1792 i. Under Gateway, click Add and select LOCAL_GG.
 - 1793 ii. Single Session Connection: Checked
 - 1794 iii. Allow Join with Active Session: Checked
 - 1795 iv. Under Recordings:
 - 1796 1) Directory: **/opt/ConsoleWorks/NCCOE/graphical**
 - 1797 2) Retain Records: **Checked**
 - 1798 3) Auto-Purge: **0**

- 1799 4) Max Size: **0**
- 1800 5) End Session when Max Size Reached: **Checked**
- 1801 6) Max Time: **0**
- 1802 v. Authentication
- 1803 1) Specify local or domain credentials, which are securely stored by
- 1804 ConsoleWorks, to allow complex passwords/credentials without having to
- 1805 share between users.
- 1806 2) Ignore Certificate Errors: Checked only if self-signed certificates are in use.
- 1807 vi. Performance
- 1808 1) Display Width: **1900**
- 1809 2) Display Height: **1200**

1810 **Table 2-21 ConsoleWorks PCS (Build 1) Graphical Connections**

Name	Device	Type	Host	Port
DMZ_HISTORIAN	DMZ_HISTORIAN	RDP	10.100.1.4	3389
PCS_HISTORIAN	PCS_HISTORIAN	RDP	172.16.2.14	3389
PCS_HMI_RDP	PCS_HMI	RDP	172.16.2.4	3389
PCS_WORKSTATION_RDP	PCS_WORKSTATION	RDP	172.16.3.10	3389

1811 Figure 2-55 ConsoleWorks List of PCS (Build 1) RDP Connections



1812 b. For Build 3 (CRS), enter the information for the graphical connections as shown in the
 1813 example (Figure 2-54) for each graphical connection listed in Table 2-22 (also shown in
 1814 Figure 2-56). For each entry, the following are common settings for all graphical connec-
 1815 tions.

1816 i. Under Gateway, click **Add** and select **LOCAL_GG**.

1817 ii. Under Recordings, use these settings:

1818 1) Directory **/opt/ConsoleWorks/NCCOE/graphical**

1819 2) Retain Records **Checked**

1820 3) Auto-Purge: **0**

1821 4) Max Size: **0**

1822 5) End Session when Max Size Reached: **Checked**

1823 6) Max Time: **0**

1824 iii. Authentication:

1825 1) Specify local or domain credentials, which are securely stored by
 1826 ConsoleWorks, to allow complex passwords/credentials without having to
 1827 share between users.

DRAFT

1828 iv. Performance

1829 1) Display Width: **1900**

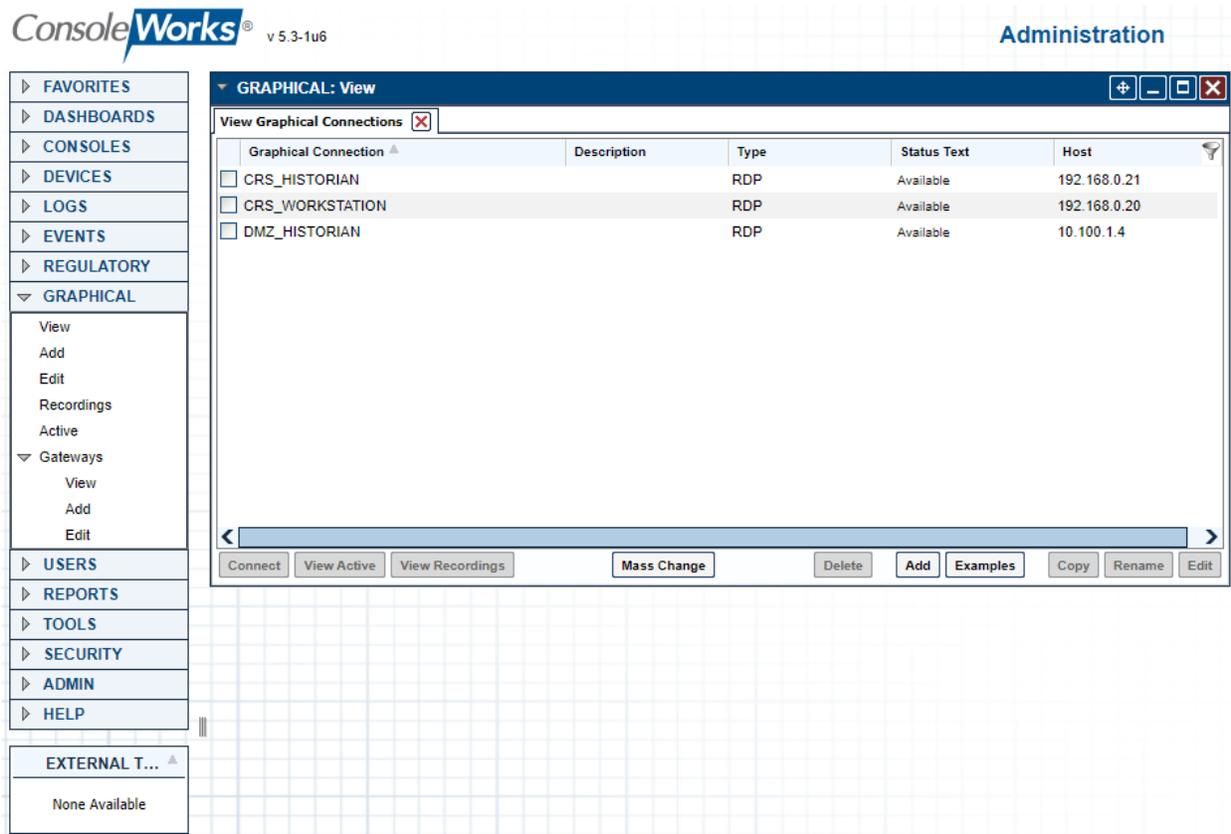
1830 2) Display Height: **1200**

1831 Table 2-22 ConsoleWorks CRS (Build 3) Graphical Connections

Name	Device	Type	Host	Port
DMZ_HISTORIAN	DMZ_HISTORIAN	RDP	10.100.1.4	3389
CRS_HISTORIAN	CRS_HISTORIAN	RDP	192.168.0.21	3389
CRS_WORKSTATION	CRS_WORKSTATION	RDP	192.168.0.20	3389

1832

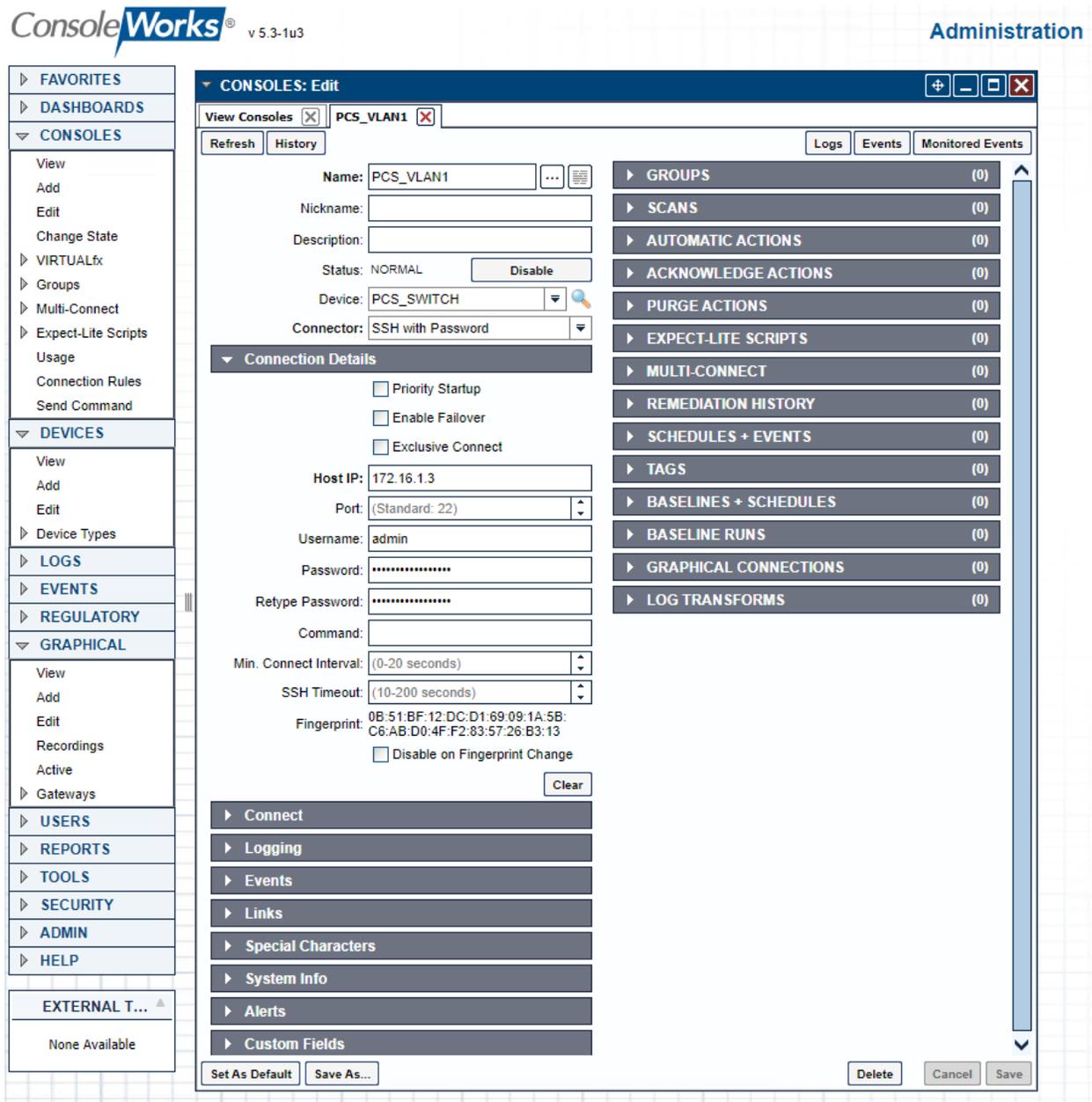
1833 Figure 2-56 ConsoleWorks List of CRS (Build 3) RDP Connections



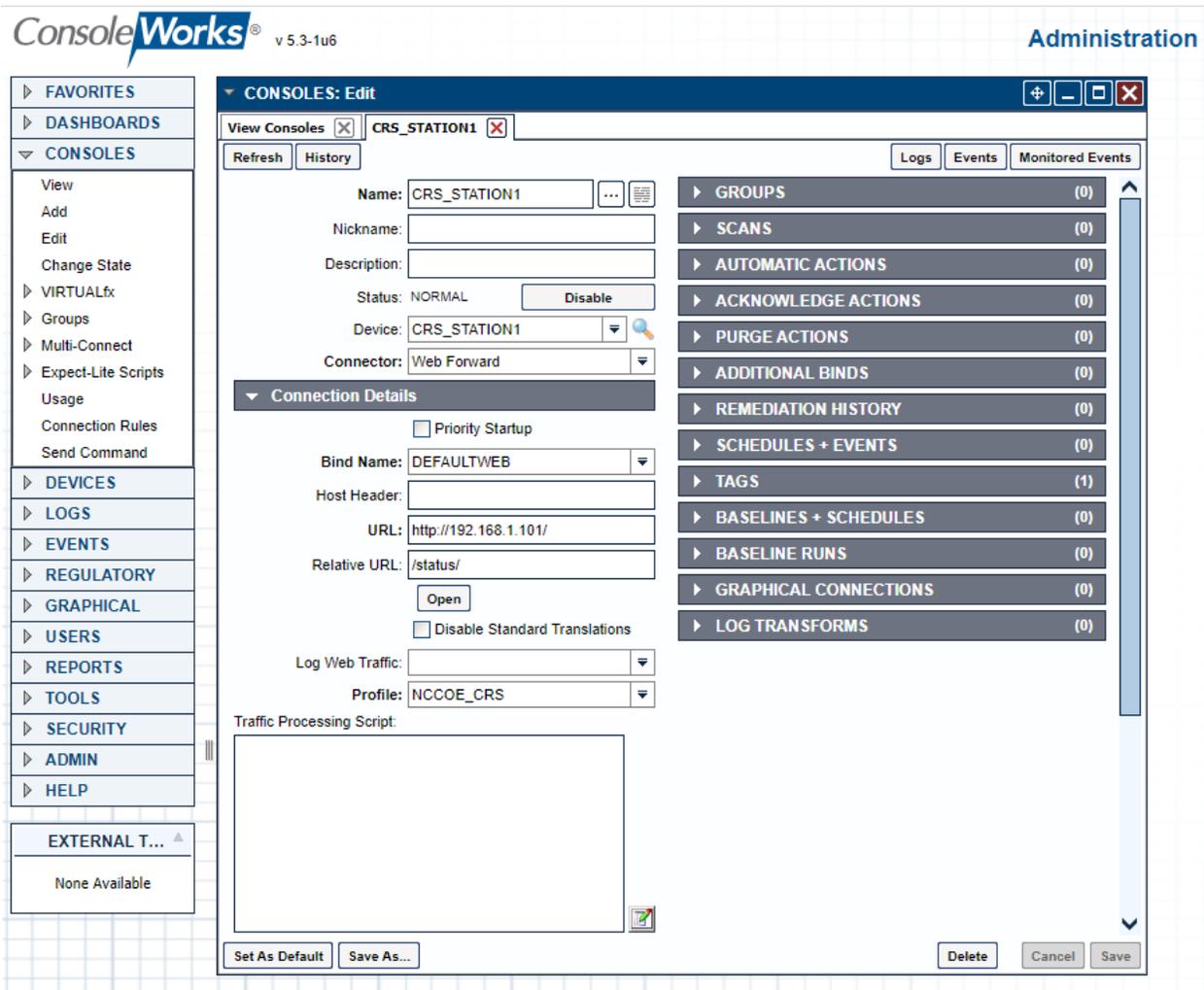
1834

1835 7. Configure console connections for non-graphical (e.g., SSH) interfaces to devices (Figure 2-57).

1836 Figure 2-57 ConsoleWorks Example Console (SSH) Connection



1837 Figure 2-58 ConsoleWorks Example Console (Web Forward) Connection



- 1838
- 1839 a. For Build 1 (PCS), enter the information for the Console Connections as shown in the ex-
- 1840 amples (Figure 2-57 and Figure 2-58) for each console connection listed in Table 2-23
- 1841 (also shown in Figure 2-59). For each entry, the following are common settings for all
- 1842 console connections.
- 1843 i. Under **Connection Details**:
- 1844 1) Specify the username and password, which are securely stored by Console-
- 1845 Works, to allow complex passwords/credentials without having to share
- 1846 between users.

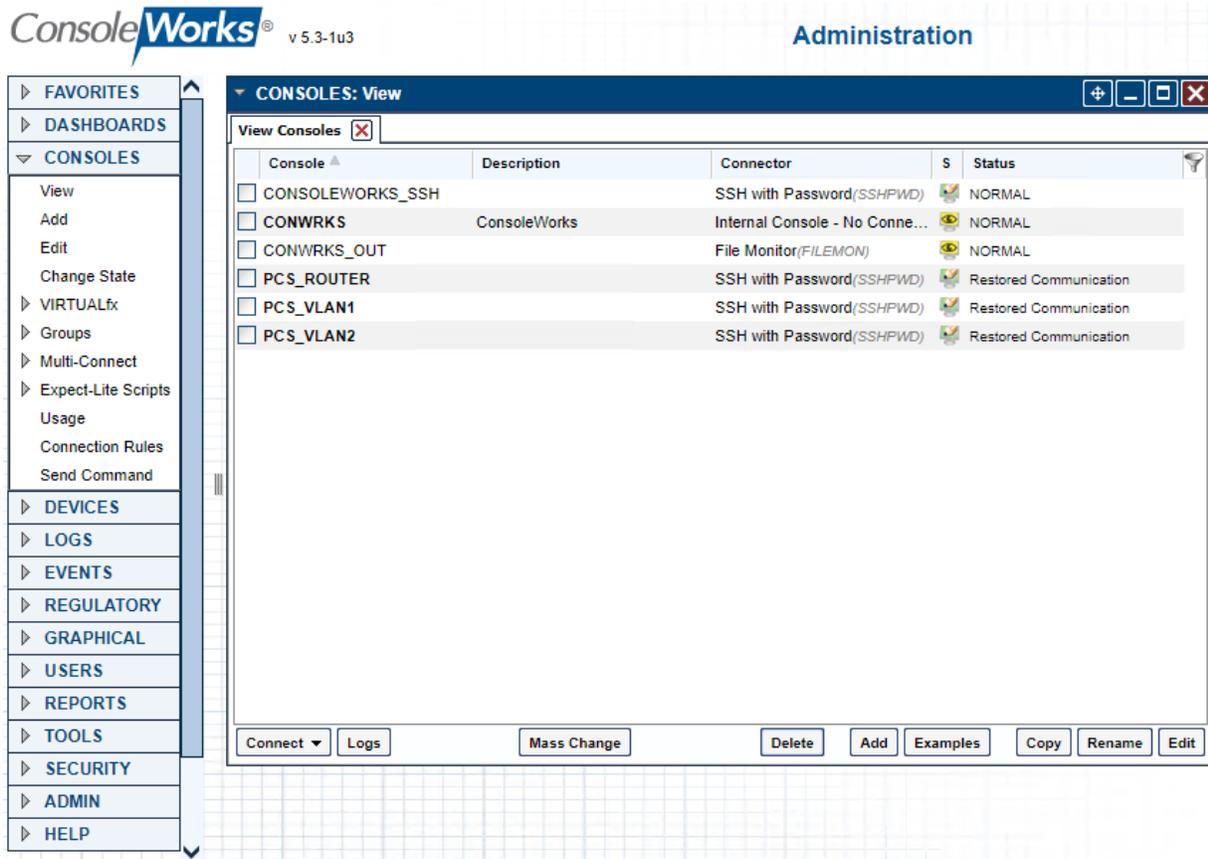
1847 Table 2-23 ConsoleWorks PCS (Build 1) Console Connections

Name	Device	Connector	Host	Port
PCS_ROUTER	PCS_ROUTER	SSH with Password	10.100.2.8	22
PCS_VLAN1	PCS_SWITCH_VLAN1	SSH with Password	172.16.1.3	22

Name	Device	Connector	Host	Port
PCS_VLAN2	PCS_SWITCH_VLAN2	SSH with Password	172.16.2.2	22

1848

1849 Figure 2-59 ConsoleWorks List of PCS (Build 1) Console Connections



1850

1851 b. For Build 3 (CRS), enter the information for the console connections as shown in the ex-
 1852 ample (Figure 2-57 and Figure 2-58) for each console connection listed in Table 2-24
 1853 (Figure 2-60). For each entry, the following are common settings for all console connec-
 1854 tions.

1855 i. Under **Connection Details**

1856 1) Specify the username and password, which are securely stored by Console-
 1857 Works, to allow complex passwords/credentials without having to share
 1858 between users.

1859 Table 2-24 ConsoleWorks CRS (Build 3) Console Connections

Name	Device	Connector	Host	Port
CRS_CONTROL_LAN	CRS_SWITCH_CONTROL	Web Forward	192.168.0.239	80
CRS_FIELD_LAN	CRS_SWITCH_FIELD	SSH with Password	192.168.1.10	22

Name	Device	Connector	Host	Port
CRS_ROUTER	CRS_ROUTER	SSH with Password	192.168.0.2	22
CRS_STATION1	CRS_STATION1	Web Forward	192.168.1.101	80
CRS_STATION2	CRS_STATION2	Web Forward	192.168.1.102	80
CRS_STATION3	CRS_STATION3	Web Forward	192.168.1.103	80
CRS_STATION4	CRS_STATION4	Web Forward	192.168.1.104	80
HMI	CRS_HMI	Web Forward	192.168.0.98	80

1860

1861 Figure 2-60 ConsoleWorks List of CRS (Build 3) Console Connections

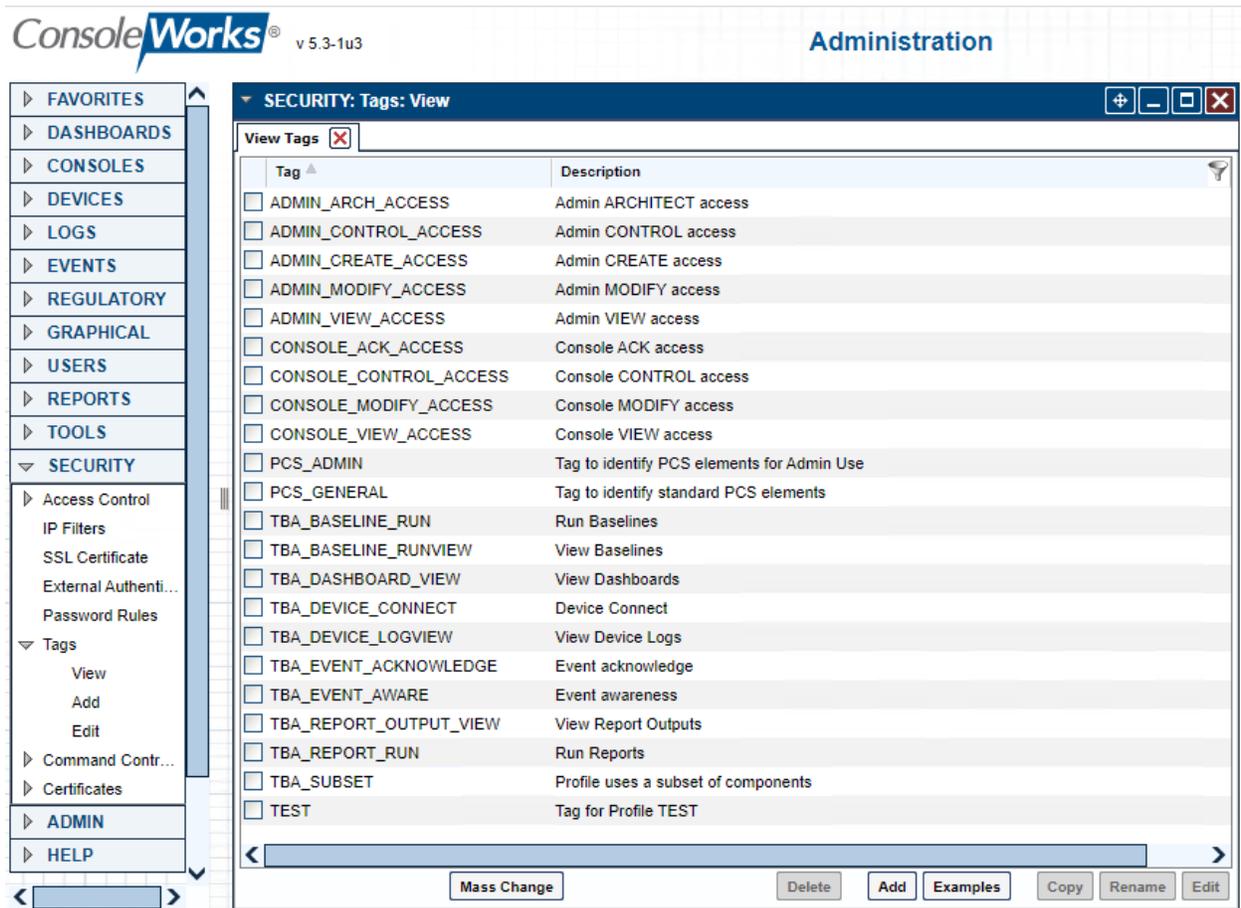
The screenshot shows the 'Administration' section of the ConsoleWorks v 5.3-1u6 interface. The 'CONSOLES' menu is expanded, and the 'CONSOLES: View' window is open. The window displays a table of console connections with columns for Console, Description, Connector, S, and Status. The table lists various consoles including CONSOLEWORKS_SSH, CONWRKS, CONWRKS_OUT, CRS_CONTROL_LAN, CRS_FIELD_LAN, CRS_ROUTER, CRS_STATION1-4, and HMI. Each row includes a checkbox, the console name, a description, the connector type, a status icon, and the current status text. Below the table are buttons for 'Connection', 'Logs', 'Mass Change', 'Delete', 'Add', 'Examples', 'Copy', 'Rename', and 'Edit'.

Console	Description	Connector	S	Status
<input type="checkbox"/> CONSOLEWORKS_SSH		SSH with Password(SSHPWD)	🚫	Waiting for User input
<input type="checkbox"/> CONWRKS	ConsoleWorks	Internal Console - No Conne...	🟢	NORMAL
<input type="checkbox"/> CONWRKS_OUT		File Monitor(FILEMON)	🟢	NORMAL
<input type="checkbox"/> CRS_CONTROL_LAN	Netgear	Web Forward(WEBFORWARD)	🟢	NORMAL
<input type="checkbox"/> CRS_FIELD_LAN	i800 Switch	SSH with Password(SSHPWD)	🟢	Restored Communication
<input type="checkbox"/> CRS_ROUTER	RuggedCom	SSH with Password(SSHPWD)	🟢	Restored Communication
<input type="checkbox"/> CRS_STATION1		Web Forward(WEBFORWARD)	🟢	NORMAL
<input type="checkbox"/> CRS_STATION2		Web Forward(WEBFORWARD)	🟢	NORMAL
<input type="checkbox"/> CRS_STATION3		Web Forward(WEBFORWARD)	🟢	NORMAL
<input type="checkbox"/> CRS_STATION4		Web Forward(WEBFORWARD)	🟢	NORMAL
<input type="checkbox"/> HMI		Web Forward(WEBFORWARD)	🟢	NORMAL

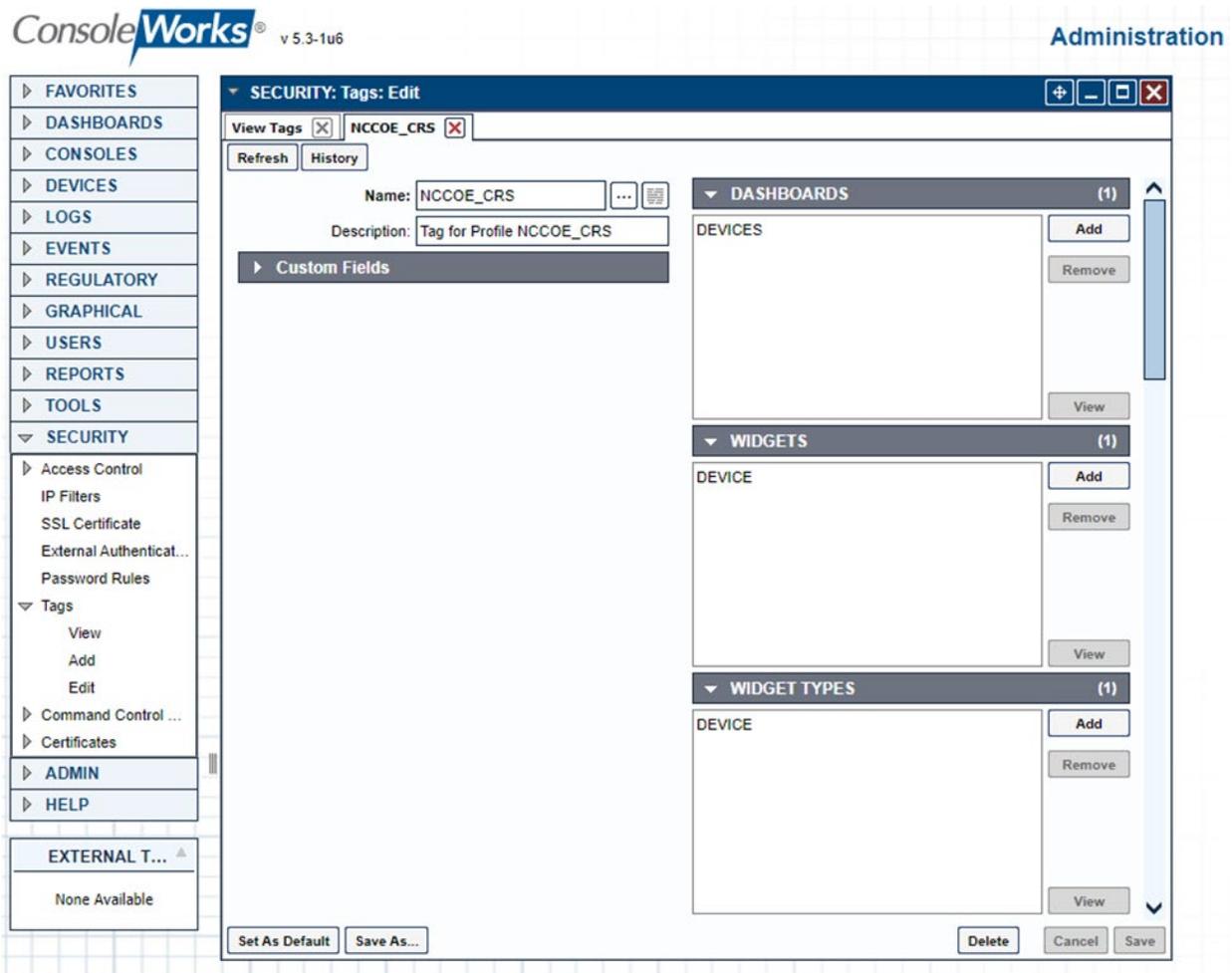
1862

1863 8. Configure tags to support profiles and access controls.

1864 Figure 2-61 ConsoleWorks List of Tags for PCS (Build 1)



1865 Figure 2-62 ConsoleWorks Example Tag Definition Screen



1866

1867 a. For Build 1 (PCS) the following tags were created as shown in Figure 2-61. Figure 2-62 shows an
 1868 example of a single tag.

1869 i. Name: **PCS_GENERAL**

1870 1) Under **Dashboards**, click **Add** and select **Devices**.

1871 2) Under **Custom UI Classes** click **Add** and select:

1872 a) DEVICE_LISTGRID

1873 b) LISTGRID

1874 3) Under **Devices**, click **Add** and select:

1875 a) DMZ_HISTORIAN

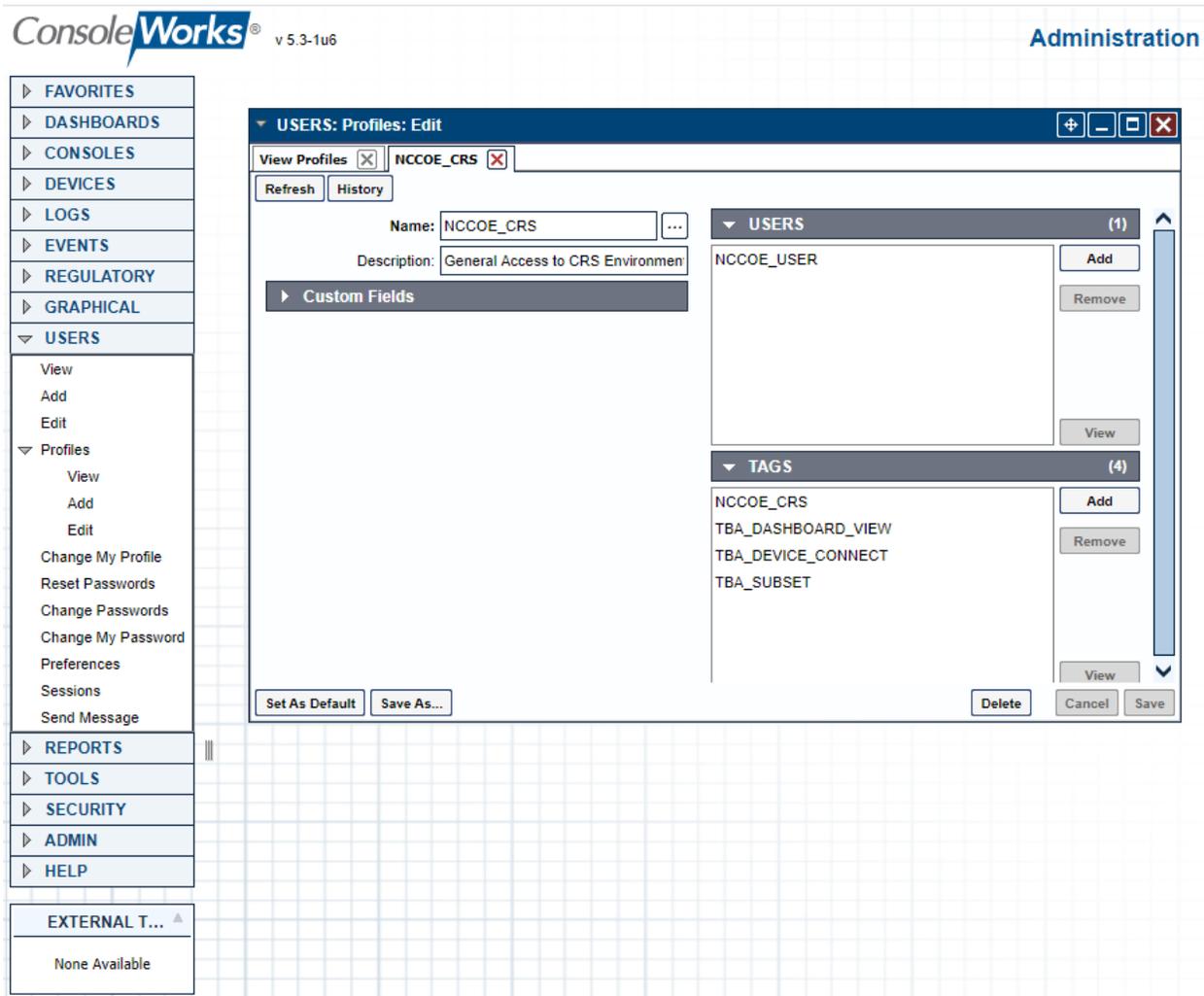
1876 b) PCS_HISTORIAN

1877 c) PCS_HMI

- 1878 i. PCS_WORKSTATION
- 1879 4) Under **Graphical Connections**, click **Add** and select:
- 1880 a) DMZ_HISTORIAN
- 1881 b) PCS_HISTORIAN
- 1882 c) PCS_HMI_RDP
- 1883 d) PCS_WORKSTATION_RDP
- 1884 ii. Name: **PCS_ADMIN**:
- 1885 1) Under **Dashboards** click **Add** and select **Devices**
- 1886 2) Under **Custom UI Classes** click **Add** and select:
- 1887 a) DEVICE_LISTGRID
- 1888 b) LISTGRID
- 1889 3) Under **Consoles**, click **Add** and select:
- 1890 a) PCS_ROUTER
- 1891 b) PCS_SWITCH_VLAN1
- 1892 c) PCS_SWITCH_VLAN2
- 1893 4) Under **Devices**, click **Add** and select:
- 1894 a) PCS_ROUTER
- 1895 b) PCS_SWITCH_VLAN1
- 1896 c) PCS_SWITCH_VLAN2
- 1897 b. For Build 3 (CRS) Create the following:
- 1898 i. Name: **NCCOE_CRS**
- 1899 1) Under **Dashboards**, click **Add** and select **Devices**.
- 1900 2) Under **Custom UI Classes**, click **Add** and select:
- 1901 a) DEVICE_LISTGRID
- 1902 b) LISTGRID
- 1903 3) Under **Consoles**, click **Add** and select:
- 1904 a) CRS_STATION1
- 1905 b) CRS_STATION2
- 1906 c) CRS_STATION3

- 1907 d) CRS_STATION4
- 1908 e) HMI
- 1909 4) Under **Devices**, click **Add** and select:
- 1910 a) CRS_HMI
- 1911 b) CRS_STATION1
- 1912 c) CRS_STATION2
- 1913 d) CRS_STATION3
- 1914 e) CRS_STATION4
- 1915 f) CRS_WORKSTATION
- 1916 5) Under **Graphical Connections**, click **Add** and select:
- 1917 a) CRS_WORKSTATION
- 1918 ii. Name: **NCCOE_ADMIN**
- 1919 1) Under Dashboards click Add and select Devices
- 1920 2) Under Custom UI Classes click Add and select:
- 1921 a) DEVICE_LISTGRID
- 1922 b) LISTGRID
- 1923 3) Under **Consoles** click **Add** and select:
- 1924 a) CRS_CONTROL_LAN
- 1925 b) CRS_FIELD_LAN
- 1926 c) CRS_ROUTER
- 1927 4) Under **Devices** click **Add** and select:
- 1928 a) CRS_SWITCH_CONTROL
- 1929 b) CRS_SWITCH_FIELD
- 1930 c) CRS_ROUTER
- 1931 9. Configure profiles to provide user accounts with granular access controls to available resources
- 1932 (Figure 2-63).

1933 Figure 2-63 ConsoleWorks Example Profile



1934

1935

- a. For Build 1 (PCS) the following profiles were created:

1936

i. **PCS_GENERAL**

1937

- 1) Under Users click Add and select

1938

- a) NCCOE_USER

1939

- 2) Under Tags click Add and select

1940

- a) PCS_GENERAL

1941

- b) TBA_DASHBOARD_VIEW

1942

- c) TBA_DEVICE_CONNECT

1943

- d) TBA_SUBSET

1944

ii. **PCS_ADMIN**

- 1945 1) Under **Users**, click **Add** and select:
- 1946 a) NCCOE_ADMIN
- 1947 2) Under **Tags**, click **Add** and select:
- 1948 a) PCS_ADMIN
- 1949 b) TBA_DASHBOARD_VIEW
- 1950 c) TBA_DEVICE_CONNECT
- 1951 d) TBA_SUBSET
- 1952 e) CONSOLE_CONTROL_ACCESS
- 1953 f) CONSOLE_VIEW_ACCESS
- 1954 b. For Build 3 (CRS) create the following:
- 1955 i. **NCCOE_CRS** profile for the NCCOE_USER with access to Tags:
- 1956 1) Under **Users**, click **Add** and select:
- 1957 a) NCCOE_USER
- 1958 2) Under **Tags** click **Add** and select the following:
- 1959 a) NCCOE_CRS
- 1960 b) TBA_DASHBOARD_VIEW
- 1961 c) TBA_DEVICE_CONNECT
- 1962 d) TBA_SUBSET
- 1963 e) CONSOLE_CONTROL_ACCESS
- 1964 f) CONSOLE_VIEW_ACCESS
- 1965 ii. **NCCOE_ADMIN** profile for the NCCOE_USER with access to Tags:
- 1966 1) Under **Users**, click **Add** and select:
- 1967 a) NCCOE_ADMIN
- 1968 2) Under **Tags** click **Add** and select the following:
- 1969 a) NCCOE_ADMIN
- 1970 b) TBA_DASHBOARD_VIEW
- 1971 c) TBA_DEVICE_CONNECT
- 1972 d) TBA_SUBSET
- 1973 e) CONSOLE_CONTROL_ACCESS

1974 f) CONSOLE_VIEW_ACCESS

1975 2.9 Tenable.OT

1976 The Tenable.OT implementation in Build 1 consists of a single appliance to meet the BAD, hardware
 1977 modification, firmware modification, and software modification capabilities. Tenable.OT utilizes a
 1978 combination of passive and active sensors to monitor critical networks for anomalies and active
 1979 querying to retrieve information about endpoints in the PCS environment.

1980 2.9.1 Host and Network Configuration

1981 Tenable.OT is installed and configured to support the PCS environment in Build 1. The overall build
 1982 architecture is described in [Figure B-1](#), and the Tenable.OT specific components are listed in Table 2-25.

1983 **Table 2-25 Tenable.OT Appliance Details.**

Name	System	OS	CPU	Memory	Storage	Network
Tenable.OT	Model: NCA-4010C-IG1	CentOS 7	Intel Xeon D-1577	64 GB	64 Gb 2 TB 2 TB	Testbed LAN 10.100.0.66

1984 2.9.2 Installation

1985 The Tenable.OT (Version 3.8.17) appliance is installed in a rack with network connections for the
 1986 Management/Query traffic on Port 1 and SPAN traffic on Port 2 of the appliance. Documentation for
 1987 Tenable.OT is available at <https://docs.tenable.com/Tenableot.htm>.

1988 2.9.3 Configuration

1989 This section outlines the steps taken to configure Tenable.OT to fully integrate and support the PCS
 1990 environment. These include setting NTP settings to synchronize the system time with the lab time
 1991 source, configuring the scanning options for the PCS environment, and configuring network objects and
 1992 policies to enhance alerting for DMZ specific remote connections.

- 1993 1. Enable connection through PCS Firewall
 - 1994 a. Add the following rules (Table 2-26) to the PCS Firewall to allow Tenable.OT to perform
 1995 asset discovery and controller scanning.

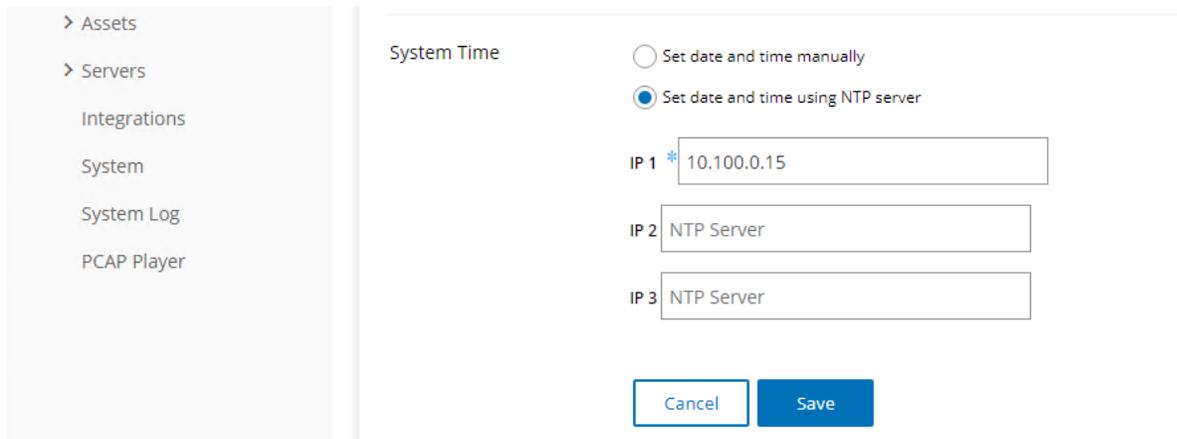
1996 **Table 2-26 Firewall Rules for Tenable.OT**

Rule Type	Source	Destination	Protocol:Port(s)	Purpose
Allow	10.100.0.66	172.16.0.0/22	ICMP	Asset Discovery
Allow	10.100.0.66	172.16.2.102	TCP:44818,2222	PLC Controller Scans

- 1997 2. Set NTP Services as follows:

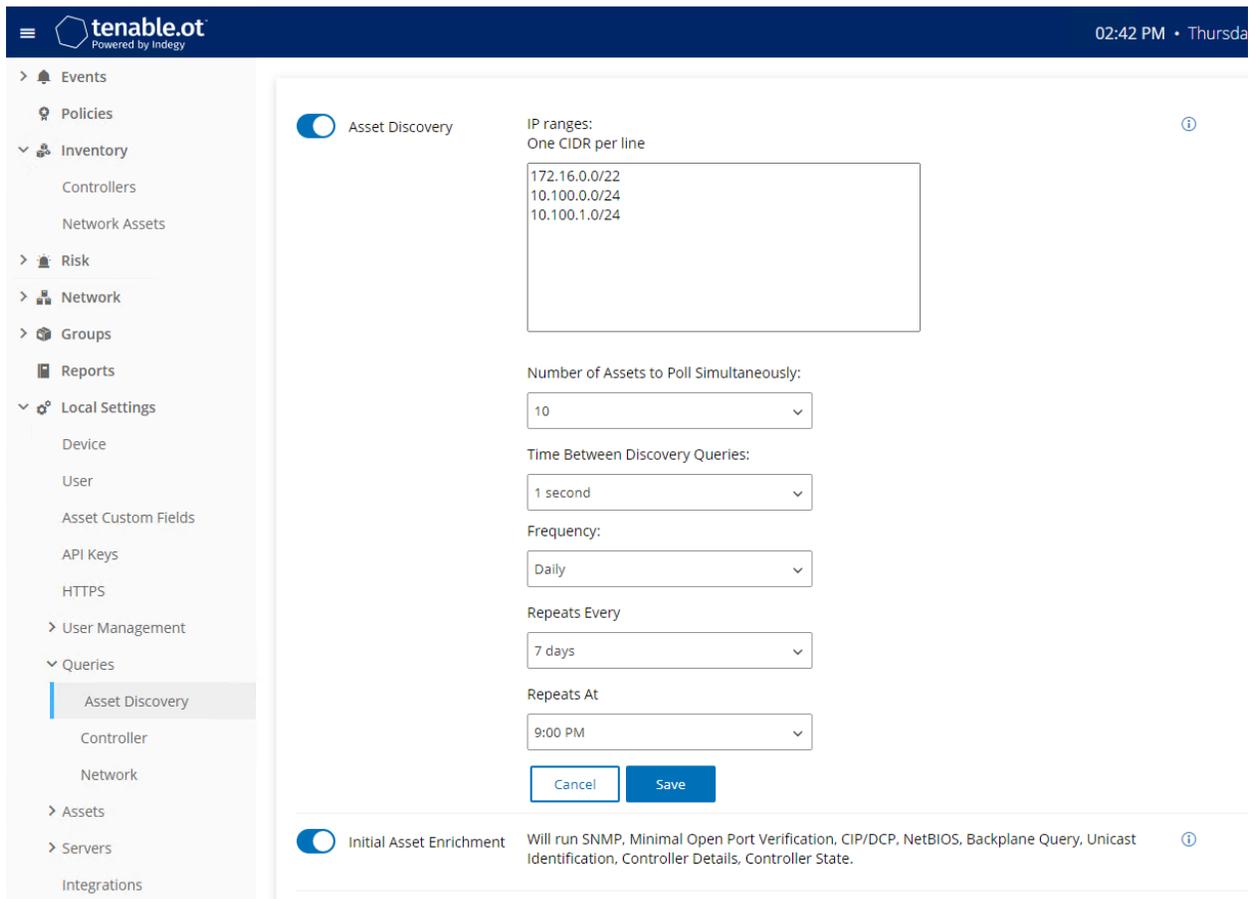
- 1998 a. After logging into the appliance, navigate to **Local Settings > Device**.
- 1999 b. To the right of System Time, click **Edit** to display the time service options (Figure 2-64).
- 2000 c. Enter the NTP Server information: **10.100.0.15**
- 2001 d. Click **Save**.

2002 **Figure 2-64 Tenable.OT Local Device Setting for NTP Service**



- 2003
- 2004 3. Configure Scanning Options as follows:
- 2005 a. Set Asset Discovery Scans:
- 2006 i. Navigate to **Local Settings > Queries > Asset Discovery** (Figure 2-65)
- 2007 ii. Enable both scan options.
- 2008 iii. Select **Edit** next to Asset Discovery.
- 2009 1) Enter the following CIDR for the PCS, DMZ, and Testbed networks:
- 2010 a) **172.16.0.0/22**
- 2011 b) **10.100.0.0/24**
- 2012 c) **10.100.1.0/24**
- 2013 2) Set the scan properties as follows:
- 2014 a) Number of Assets to Poll Simultaneously: **10**
- 2015 b) Time Between Discovery Queries: **1 second**
- 2016 c) Frequency: **Daily**
- 2017 d) Repeats Every: **7 Days**
- 2018 e) Repeats at: **9:00 PM**
- 2019 3) Click **Save**.

2020 **Figure 2-65 Tenable.OT Asset Discovery Settings**



2021

2022

b. Set Controller Scans as follows:

2023

i. Navigate to **Local Settings > Queries > Controller** (Figure 2-66)

2024

ii. Enable the following options:

2025

1) All Controller Queries

2026

2) Periodic Snapshots

2027

3) Controller Discovery

2028

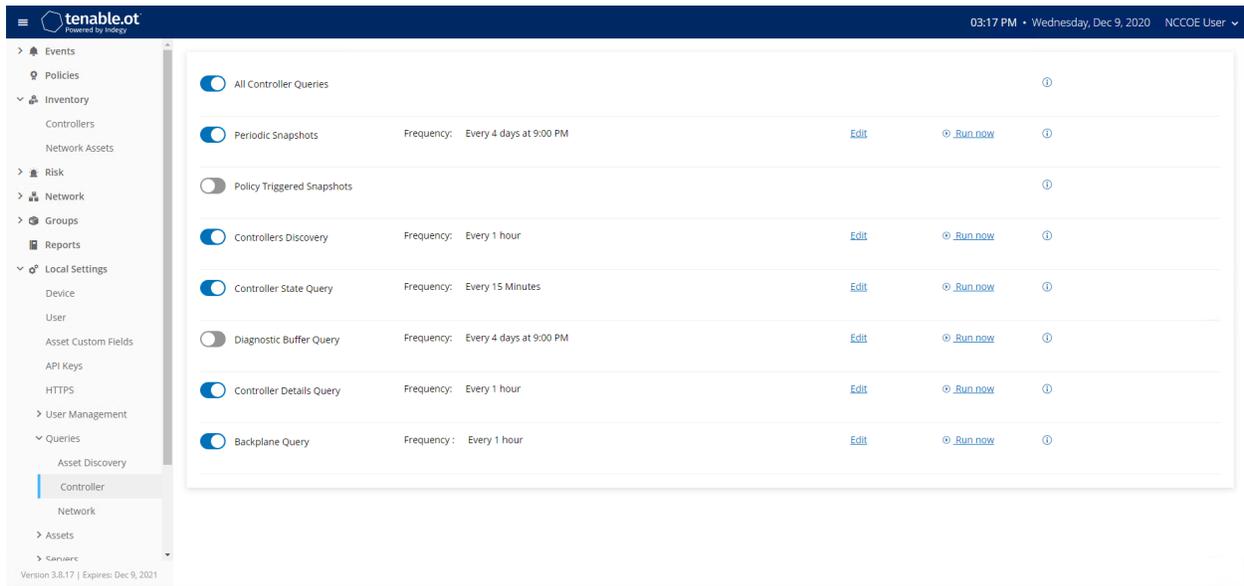
4) Controller Status Query

2029

5) Controller Details Query

2030

6) Backplane Query

2031 **Figure 2-66 Tenable.OT Controller Scans**

2032

2033

c. Set Network Scans as follows:

2034

i. Navigate to Local Settings > Queries > Network (Figure 2-67)

2035

ii. Enable the following options:

2036

1) All Network Queries

2037

2) DNS Query

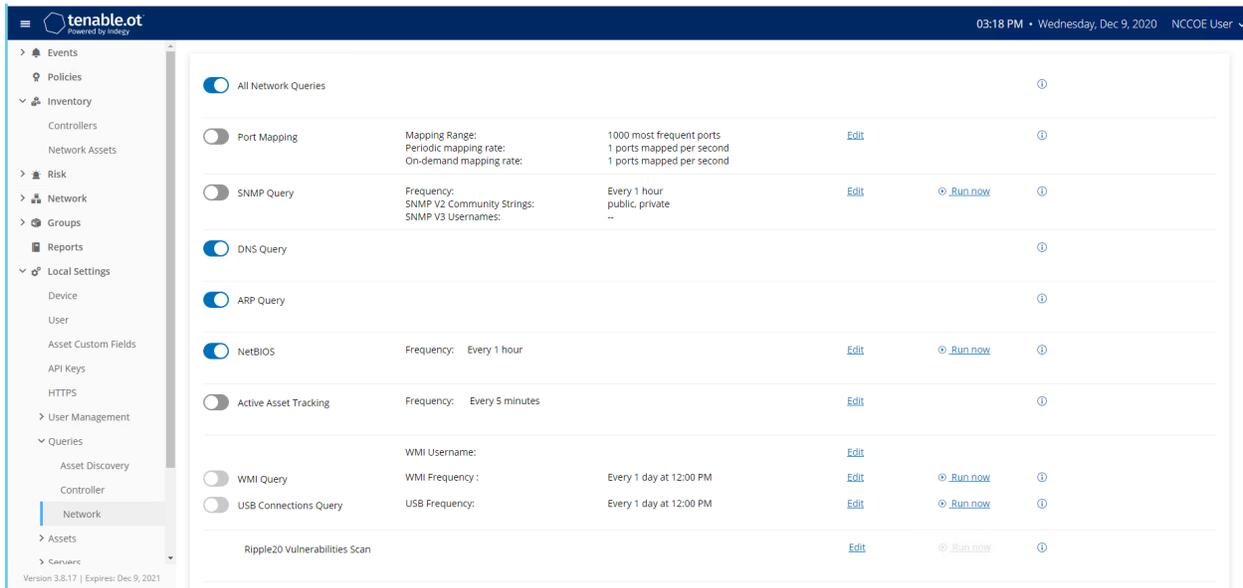
2038

3) ARP Query

2039

4) NetBIOS Query

2040 Figure 2-67 Tenable.OT Network Scan Settings



2041

2042 4. Create Group Object as follows:

2043

a. Set DMZ Group Object

2044

i. Navigate to Groups > Asset Groups

2045

ii. Click Create Asset Group to initiate the Wizard process.

2046

1) Select **IP Range** for the Asset Group Type (Figure 2-68) and Click **Next**.

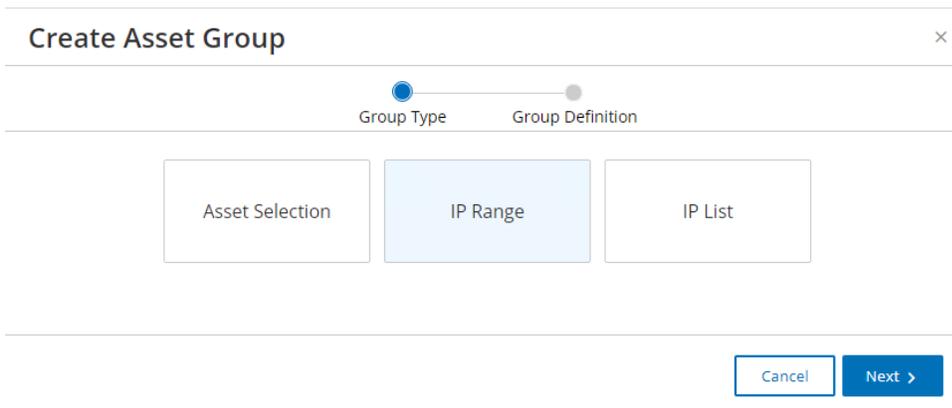
2047

2) Enter the asset name in Name, the starting IP address in Start IP, and the

2048

ending IP Address in End IP (Figure 2-69) and Click **Create**.

2049 Figure 2-68 Tenable.OT Create Asset Group Type



2050 Figure 2-69 Tenable.OT Create Asset Group Definition

2051

2052 5. Create Policy to Detect External RDP Traffic:

2053 a. In the left side navigation, click **Policies**.2054 b. Click **Create Policy** in the upper right corner of the page (Figure 2-70), then follow these
2055 steps:2056 i. For the Event Type (Figure 2-71), select as **a Network Events > RDP Connection**
2057 **(Authenticated)** and click **Next**.2058 ii. For the Policy Definition (Figure 2-72), specify the following parameters and click
2059 **Next**:

2060 1) Policy Name: Enter "External RDP Communications"

2061 2) Source Group: Select "In" from the first drop-down, and "DMZ" from the
2062 second drop-down.2063 3) Destination Group: Select "In" from the first drop-down and select "In Any
2064 Asset" from the second drop-down.2065 4) Schedule Group: Select "In" from the first drop-down, and "In Any Time"
2066 from the second drop-down.2067 iii. For the Policy Action (Figure 2-73), select **Medium** Sensitivity and click **Create**.

2068 Figure 2-70 Tenable.OT Policy Settings

STATUS	NAME	SEVERITY	EVENT TYPE	CATEGORY	SOURCE	DESTINATION / A...	SCHEDULE
<input type="checkbox"/>	SIMATIC Code Download	Medium	SIMATIC Code Do...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time
<input type="checkbox"/>	SIMATIC Code Upload	Low	SIMATIC Code Uplo...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time
<input type="checkbox"/>	SIMATIC Code Delete	Medium	SIMATIC Code Del...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time
<input type="checkbox"/>	SIMATIC Hardware Configuration Download	Medium	SIMATIC Hardwar...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time
<input type="checkbox"/>	SIMATIC Hardware Configuration Upload	Low	SIMATIC Hardwar...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time
<input type="checkbox"/>	SIMATIC Firmware Download	High	SIMATIC Firmwar...	Configuration Eve...	In Any Asset	In Any Asset	In Any Time

2069

2070 Figure 2-71 Tenable.OT Create Policy – Event Type Options

Create Policy [X]

Event Type Policy Definition Policy Actions

Search... [Q]

- A new asset has been detected in the network by Tenable.ot
- Open port**
The asset listens and is responsive over a particular TCP port
- Spike in network traffic**
A spike in the network traffic throughput has been detected
- Spike in conversation**
A spike in the number of conversations over the network has been detected
- RDP Connection (Authenticated)**
An authenticated initiation of an RDP connection
- RDP Connection (not Authenticated)**
An unauthenticated initiation of an RDP connection
- Unauthorized Conversation**
A conversation in an unauthorized protocol has been detected

Items: 167

[Cancel] [Next >]

2071 Figure 2-72 Tenable.OT Create Policy - Definition

Create Policy [Close]

Event Type Policy Definition Policy Actions

RDP Connection (Authenticated)

POLICY NAME *
External RDP Communications

SOURCE GROUP *
In [v] DMZ [v] + Or [v]
+ And

DESTINATION *
In [v] Any Asset [v] + Or [v]
+ And

SCHEDULE GROUP *
In [v] Any Time [v]

< Back Cancel Next >

2072 Figure 2-73 Tenable.OT Create Policy - Actions

Create Policy ×

Event Type Policy Definition Policy Actions

RDP Connection (Authenticated)

SEVERITY *

High Medium Low None

SYSLOG
Syslog servers are not configured

EMAIL GROUP
SMTP servers are not configured

ADDITIONAL ACTIONS
 Disable after first hit

< Back Cancel Create

2073 2.10 VMware Carbon Black App Control

2074 VMware Carbon Black App Control is an endpoint protection tool that provides multiple file integrity
 2075 and application features, including application allow/deny listing and file modification or deletion
 2076 protection. Carbon Black was used for Builds 1 and 4 as the application allowlisting (AAL) and file
 2077 integrity checking tool.

2078 2.10.1 Host and Network Configuration

2079 The following tables (Table 2-27, Table 2-28, and Table 2-29) detail the host and network configuration
 2080 of the Carbon Black App Control server for PCS and CRS.

2081 Table 2-27 Carbon Black App Control Domain Hosts Deployment

Name	System	OS	CPU	Memory	Storage	Network
Carbon Black Server	VMware ESXi VM	Windows Server 2016 Datacenter	4	8GB	500GB	Testbed LAN 10.100.0.52
Windows Server	Hyper-V VM	Windows Server 2012 R2	2	6GB	65GB	Testbed LAN 10.100.0.25
OSIsoft Pi Server	Hyper-V VM	Windows Server 2016 Standard	4	8GB	80GB/171GB	DMZ 10.100.1.4
Dispel VDI	Hyper-V VM	Windows Server 2016 Datacenter	2	8GB	126GB	N/A

2082 Table 2-28 Carbon Black App Control PCS Hosts Deployment

Name	System	OS	CPU	Memory	Storage	Network
PCS HMI Workstation	Supermicro Z97X-Ud5H	Windows 7	4	8GB	233GB	PCS 172.16.1.4
PCS Engineering Workstation	Supermicro Z97X-Ud5H	Windows 7	4	16GB	465GB	PCS 172.16.3.10

2083 Table 2-29 Carbon Black App Control CRS Hosts Deployment

Name	System	OS	CPU	Memory	Storage	Network
CRS Engineering Workstation	Dell Precision T5610	Windows 10	8	16GB	465GB	CRS Supervisory 192.168.0.20
CRS OSIsoft Pi Server	Hyper-V VM	Windows Server 2016 Standard	4	16GB	80GB/171GB	CRS Supervisory 192.168.0.21

2084

2.10.2 Installation

2085 Prepare the Carbon Black App Control Server (fka CB_Protection) in accordance with the CB Protection
 2086 Operating Environment Requirements v8.1.6 document that is provided for installation. This document,
 2087 and all Carbon Black documentation, can be found on the website <https://community.carbonblack.com>.

2088 1. Install Carbon Black App Control Server (fka CB_Protection) using these steps:

- 2089 a. Created nccoeCarbon domain user account on LAN AD to be used for installation and
2090 administration of CB App Control Server and add this user to the local administrators'
2091 group on the server.
- 2092 b. Install SQL Server Express 2017 according to the CB Protection SQL Server Configuration
2093 v8.1.4 document.
- 2094 c. Install the CB App Control Server according to the CB Protection Server Install Guide
2095 v8.1.6 document.

2096 2.10.3 Configuration

2097 Follow these steps to configure Windows Server 2016:

- 2098 1. On the Carbon Black App Control Server, configure Windows Server 2016:
- 2099 a. Based on Carbon Black documentation (Figure 2-74), Windows Server 2016 will need to
2100 have the following features for the Internet Information Services (IIS) role enabled for
2101 Carbon Black to work (Figure 2-75).

2102 Figure 2-74 Excerpt from Carbon Black Documentation on Support Server Requirements

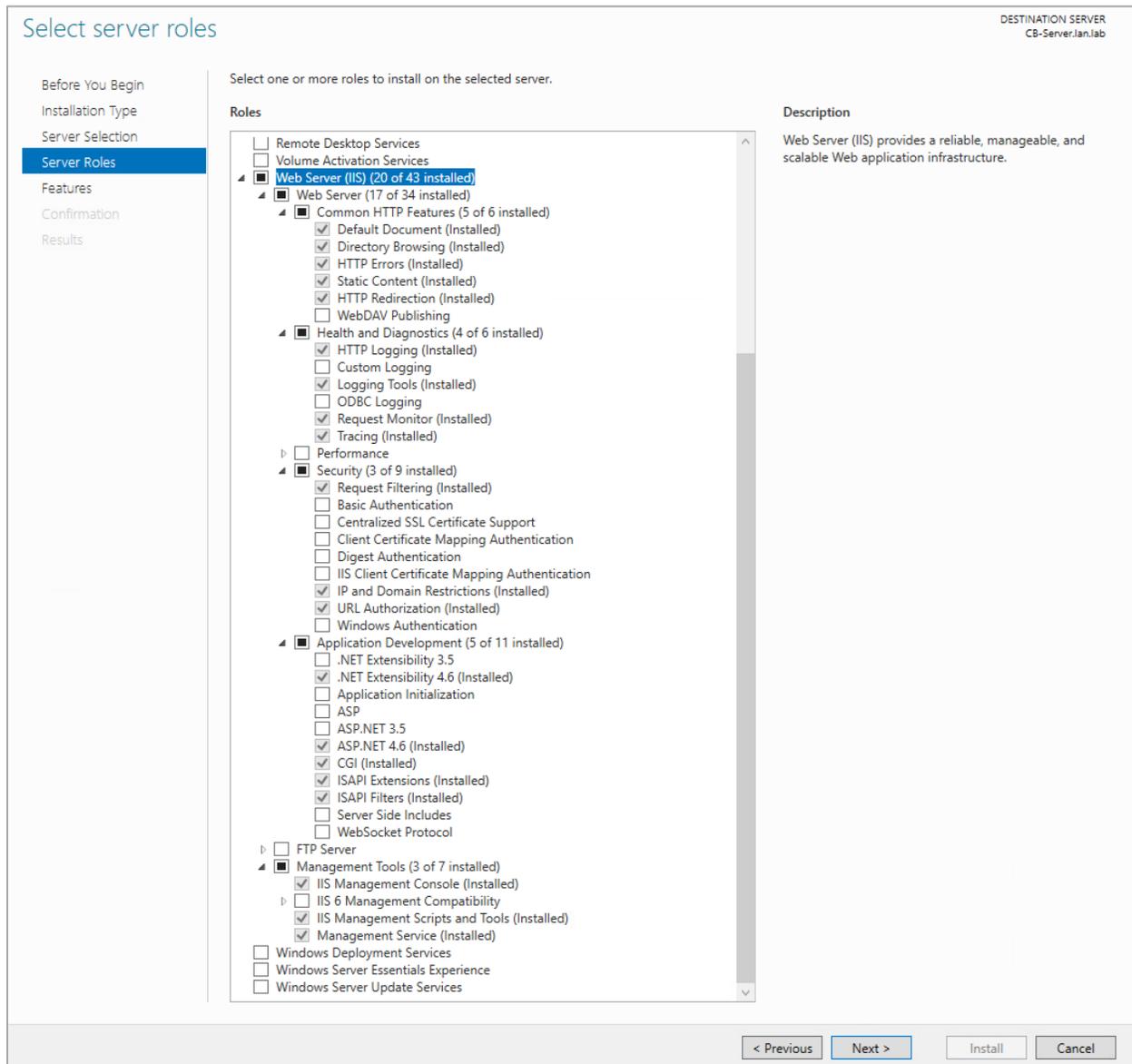
Carbon Black.

CB Protection Web Server Platform: Support Server

Common Requirements ①	Restrictions ②
<p>In the IIS Roles Manager, verify the following configuration:</p> <ul style="list-style-type: none"> • Common HTTP Features: <ul style="list-style-type: none"> - Static Content - Default Document - HTTP Errors - HTTP Redirection • Application development: <ul style="list-style-type: none"> - ASP.NET (version 4.5) - .NET Extensibility (version 4.5) - CGI - ISAPI Extensions - ISAPI Filters • Health & Diagnostics: <ul style="list-style-type: none"> - HTTP Logging - Logging Tools - Request Monitor - Tracing • Security: <ul style="list-style-type: none"> - URL Authorization - Request Filtering - IP and Domain Restrictions • Performance: None • Management Tools: <ul style="list-style-type: none"> - IIS Management Console - IIS Management Scripts and Tools - Management Service • FTP Publishing Service: None 	<p>Beginning with v8.0.0, the console relies on the CB Protection API. An incorrectly configured IIS server can prevent console access.</p> <ul style="list-style-type: none"> • To confirm API functionality, go to System Configuration > Advanced Options in your current console and check the "API Access Enabled" box. If a green dot appears next to the checkbox, then you can assume that IIS is configured correctly. Otherwise, make sure you meet the following restrictions: <ul style="list-style-type: none"> • Site Bindings: <p>The CB Protection API will not connect to localhost if the console web application is bound to a specific IP address instead of "*". Make sure that "*" is added to the list of bindings.</p> • IP Address and Domain Restrictions: <p>If you must limit console access to specific IP addresses, be sure that the IPv6 localhost address is added to the list.</p> • Application Pools: <p>CB Protection must be run within the DefaultAppPool application pool. Using a different app pool results in the CB Protection server not having the appropriate credentials to access the SQL Server database.</p> • Authentication: <p>You must disable Basic Authentication and Windows Authentication so that the CB Protection Server handles authentication. Otherwise, users will not be able to log into the CB Protection Server.</p>

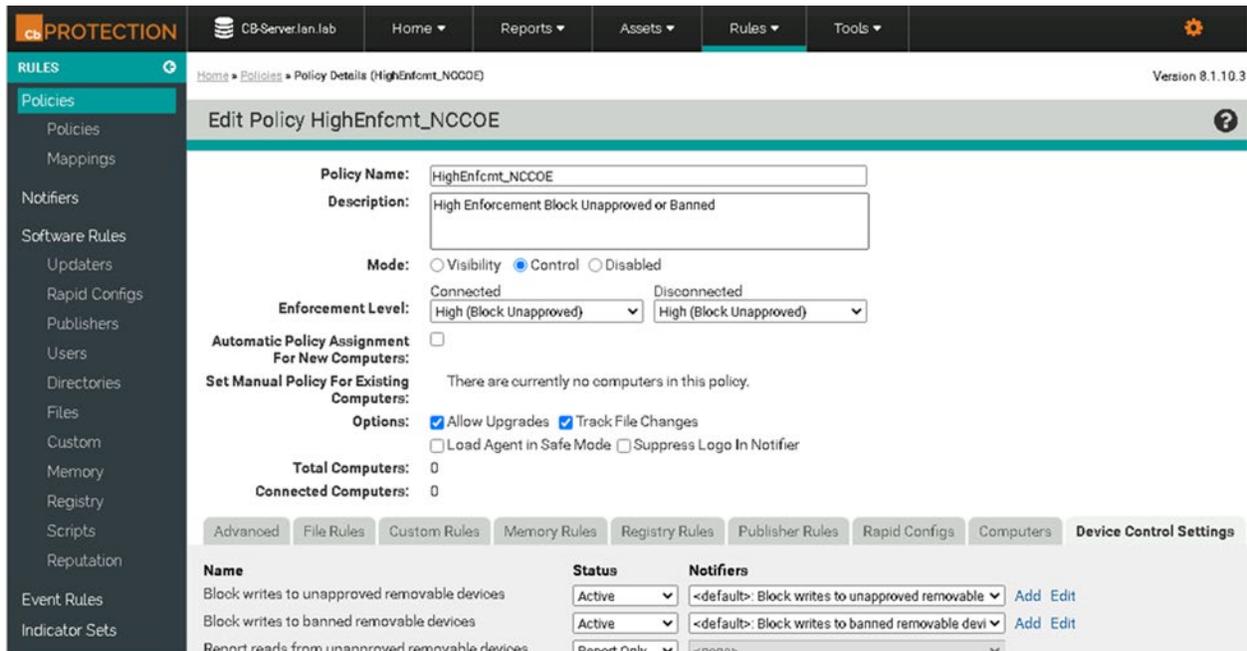
Version	Part Of OS	Current Version	Supported Architecture	Supported Level	Additional Notes/Requirements
IIS 8.5	Windows 2012 Server R2 only		x64		① ② Common Requirements and Restrictions are listed in the table above Additional requirements: Private memory for IIS should be increased to 800 MB
IIS 10	Windows 2016 Server		X64		① ② Common Requirements and Restrictions are listed in the table above Additional requirements: Private memory for IIS should be increased to 800 MB

2103 Figure 2-75 IIS Configuration for Carbon Black, Server Roles



- 2104 2. Manually update the Windows Server firewall configuration to allow inbound port 41002 traffic
 2105 from CB App Control clients/agents.
 2106 3. Configure Policy in the Carbon Black Console using these steps:
- 2107 a. In the CB App Control Console, go to **Rules > Policies**.
- 2108 b. Create a new policy with the desired enforcement level. In this case, a high enforcement
 2109 level was chosen to actively block execution of unapproved or banned executables (Fig-
 2110 ure 2-76).

2111 Figure 2-76 Carbon Black Policy Edit



2112

2113 4. Enable AD Integration Features as follows:

- 2114 a. Enable AD integration features on CB App Control Console for domain user account
- 2115 login and AD-Based Policy mapping. AD-Based Policy mapping allows automatic policy
- 2116 assignment to be mapped to AD users, groups, computers, organizational units (OUs),
- 2117 etc., as configured by a CB App Control Console administrator (Figure 2-77).

2118 Figure 2-77 Carbon Black App Control System Configuration

The screenshot displays the Carbon Black App Control System Configuration interface. The top navigation bar includes 'cb PROTECTION' and a user profile 'CB-Server.lan.lab'. Below this, a secondary navigation bar lists 'General', 'Events', 'Security', 'Advanced Options', 'Mail', 'Licensing', 'External Analytics', 'Connectors', and 'SAML Login'. The left sidebar, under 'ADMINISTRATION', lists 'Login Accounts' (Users, User Roles, User Role Mappings), 'System Configuration' (General, Events, Security, Advanced Options, Mail, Licensing, External Analytics, Connectors, SAML Login), and 'System Health' (Update Agent/Rule Versions). The main content area is titled 'General Settings' and is divided into sections: 'Server Status' (displaying version, address, port, timezone, database details, and disk space), 'Active Directory / LDAP integration' (showing AD-based logins, security domain, policy, and a successful connectivity test), and 'Agent Management'.

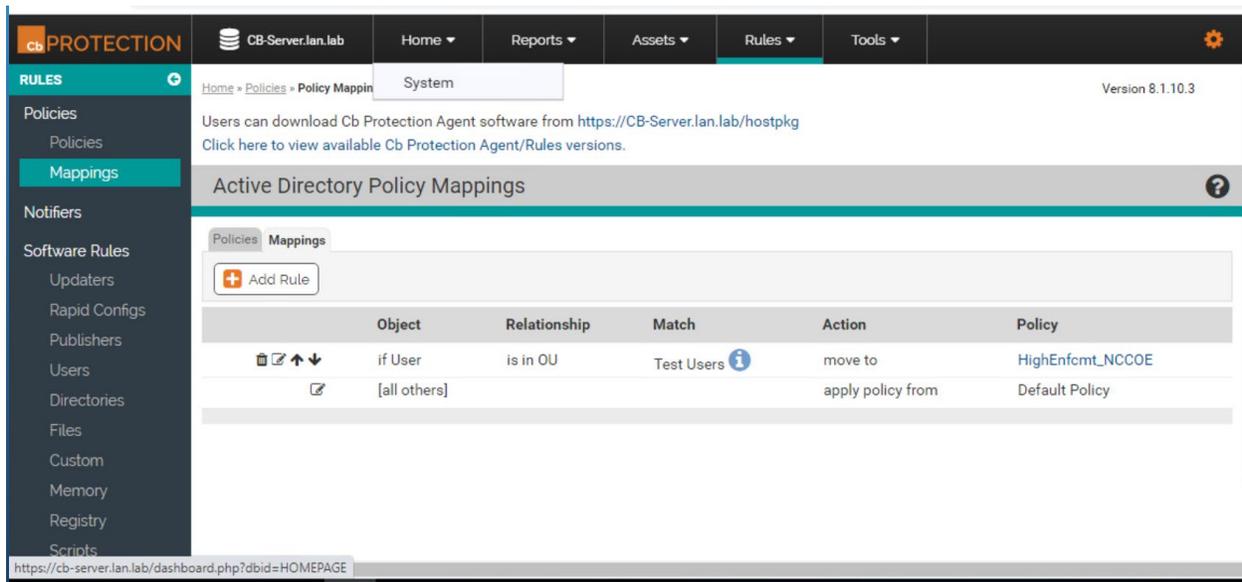
2119

2120 5. Add users from AD and assign policies:

2121 a. Add "Test Users" OU from the AD to policy mapping settings and assign the "High-
2122 Enfcmt_NCCOE" policy (Figure 2-78).

2123 This OU includes the "nccoeUser" and "nccoeAdmin" user accounts created for the test
2124 scenarios. This policy will be automatically applied to these users logged in on any com-
2125 puter that is running the CB Protection Agent. The "HighEnfcmt_NCCOE" policy is set to
2126 High Enforcement level, which will actively block all unapproved or banned files, applica-
2127 tions, or devices.

2128 Figure 2-78 Carbon Black App Control AD Policy Mappings



2129

2130 6. Download and install CB App Control Agent from CB App Control Server

2131 (The process outlined below uses the CRS Engineering Workstation as an example, but the process
2132 was the same for all the agent computers.). Follow these steps:

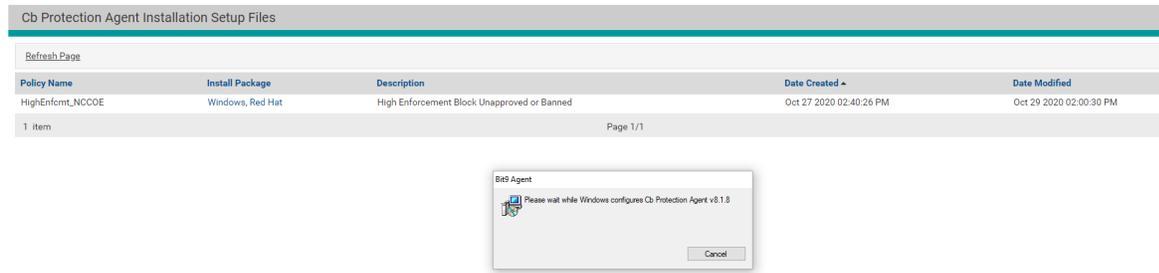
2133 a. Open the browser on the CRS Engineering Workstation and enter the URL to download
2134 the agent installer: <https://CB-Server.lan.lab/hostpkg>. This URL is on the Carbon Black
2135 server itself and is accessed on the local network. CB-Server.lan.lab is the full host name
2136 we gave this server during installation.

2137 i. If the host cannot access CB-Server.lan.lab, update the environment DNS Server
2138 by mapping the IP address, 10.100.0.52, to CB-Server.lan.lab or add the mapping
2139 to the local host file.

2140 b. Download the Windows CB App Control Agent installer from the CB App Control Server
2141 and install on the CRS Engineering Workstation (Figure 2-79).

2142 **Figure 2-79 Carbon Black Agent Download**

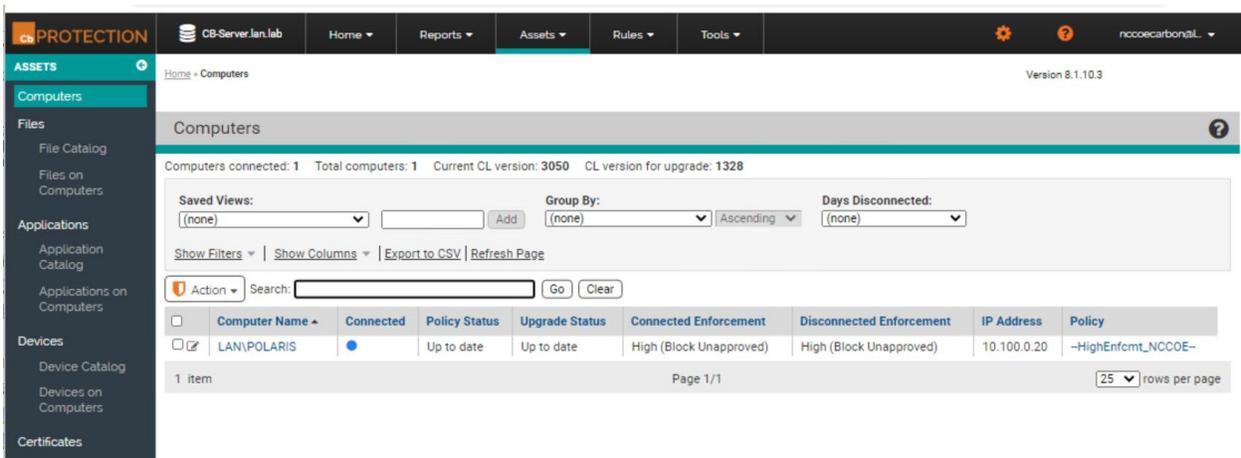
- Installing the Cb Protection Agent software is simple:
1. Click the installation setup file for the policy assigned to you by your network administrator.
 2. Download the installation setup file to a convenient location on your hard-drive.
 3. From the download directory, double-click the newly downloaded file to install Cb Protection Agent.



2143

- 2144 c. Check the CB App Control Console to verify communication and initialization of the new
 2145 CRS Engineering Workstation agent computer on the CB App Control Server (Figure
 2146 2-80).

2147 **Figure 2-80 Carbon Black App Control Computers**

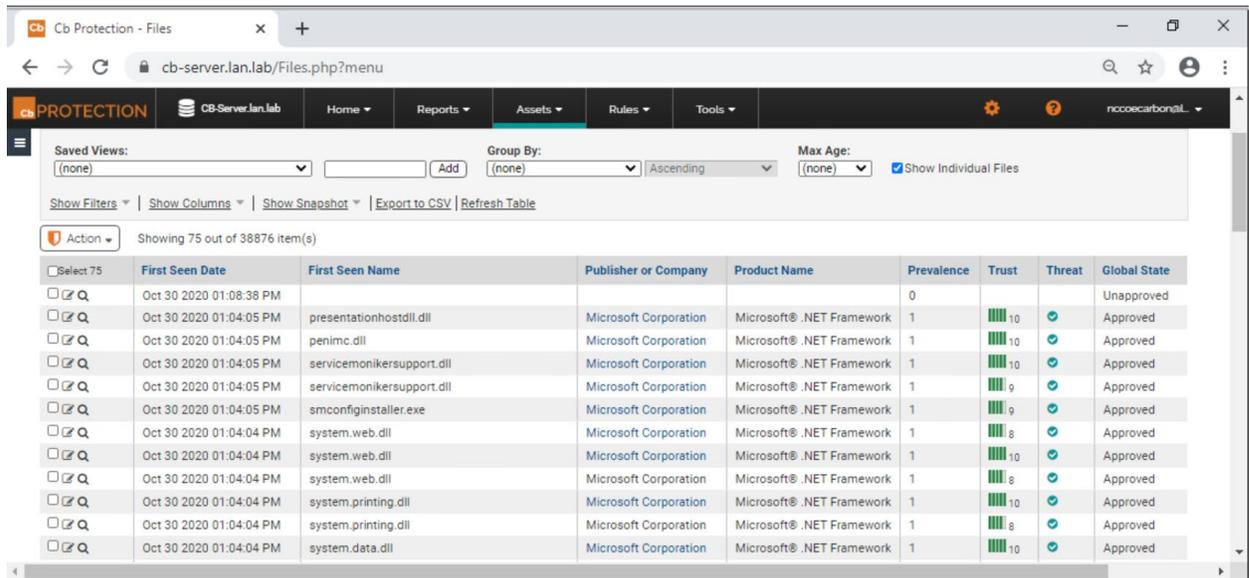


2148

- 2149 d. Approve all new trusted files and publishers that were added from the CRS Engineering
 2150 Workstation to the catalog on the CB App Control Server.

- 2151 e. This image (Figure 2-81) shows the Cb Protection - Files page of the CB App Control Con-
 2152 sole.

2153 **Figure 2-81 Carbon Black App Control File Catalog**



2154

2155 **2.11 Windows Software Restriction Policy (SRP)**

2156 Windows SRP is a feature that is a part of the Windows operating system. It identifies applications that
 2157 are running on any domain-controlled computer, and it can block any programs that have not been
 2158 allow-listed. Configuring Windows SRP is done through Group Policy Object management. Windows SRP
 2159 was used for AAL in Builds 2 and 3.

2160 **2.11.1 Host and Network Configuration**

2161 Windows SRP configuration is established by Group Policy Objects (GPOs) located on the two AD
 2162 servers. The domain controllers were common across all builds as detailed in Table 2-30.

2163 **Table 2-30 Windows SRP Domain Servers**

Name	System	OS	CPU	Memory	Storage	Network
AD (Primary) Server	Hyper-V VM	Windows 2012R2	2x vCPU	2 GB	45 GB	Testbed LAN 10.100.0.17
AD (Secondary) Server	Hyper-V VM	Windows 2012R2	1x vCPU	2 GB	21 GB	Testbed LAN 10.100.0.13

2164

2165 The following systems were configured to utilize Windows SRP for each build. Additional details for each
 2166 build are available in Section 4.5 of Volume B.

2167 Build 2 supports the testing within the PCS environment. The overall build architecture is provided in
 2168 [Figure B-2](#). The Windows SRP specific components are in Table 2-31.

2169 **Table 2-31 Windows SRP Build 2 Deployment**

Name	System	OS	CPU	Memory	Storage	Network
Windows Server	Hyper-V VM	Windows 2012R2	2x vCPU	6 GB	65 GB	Testbed LAN 10.100.0.25
Dispel VDI	Hyper-V VM	Windows 2016	2x vCPU	8 GB	126 GB	DMZ LAN 10.100.1.61
DMZ Historian	Hyper-V VM	Windows 2016	4x vCPU	8 GB	80 GB, 171 GB	DMZ LAN 10.100.1.4
Engineering Workstation	HP Z230 Workstation	Windows 7	Intel i5-4570	16 GB	465 GB	172.16.3.10
HMI Host	Generic	Windows 7	Intel i5-4590	8 GB	233 GB	PCS VLAN 1 172.16.1.4

2170 Build 3 supports the testing within the CRS environment. The overall build architecture is provided in
 2171 [Figure B-3](#). The Windows SRP specific components are in Table 2-32.

2172 **Table 2-32 Windows SRP Build 3 Deployment**

Name	System	OS	CPU	Memory	Storage	Network
Windows Server	Hyper-V VM	Windows 2012R2	2x vCPU	6 GB	65 GB	Testbed LAN 10.100.0.25
DMZ Historian	Hyper-V VM	Windows 2016	4x vCPU	8 GB	80 GB, 171 GB	DMZ LAN 10.100.1.4
Engineering Workstation	Dell T5610	Windows 10	2x Intel E3-2609 v2	16 GB	465 GB	CRS Supervisory LAN 192.168.0.20
CRS Local Historian	Hyper-V VM	Windows 2016	4x vCPU	16 GB	80 GB, 171 GB	CRS Supervisory LAN 192.168.0.21

2173 2.11.2 Installation

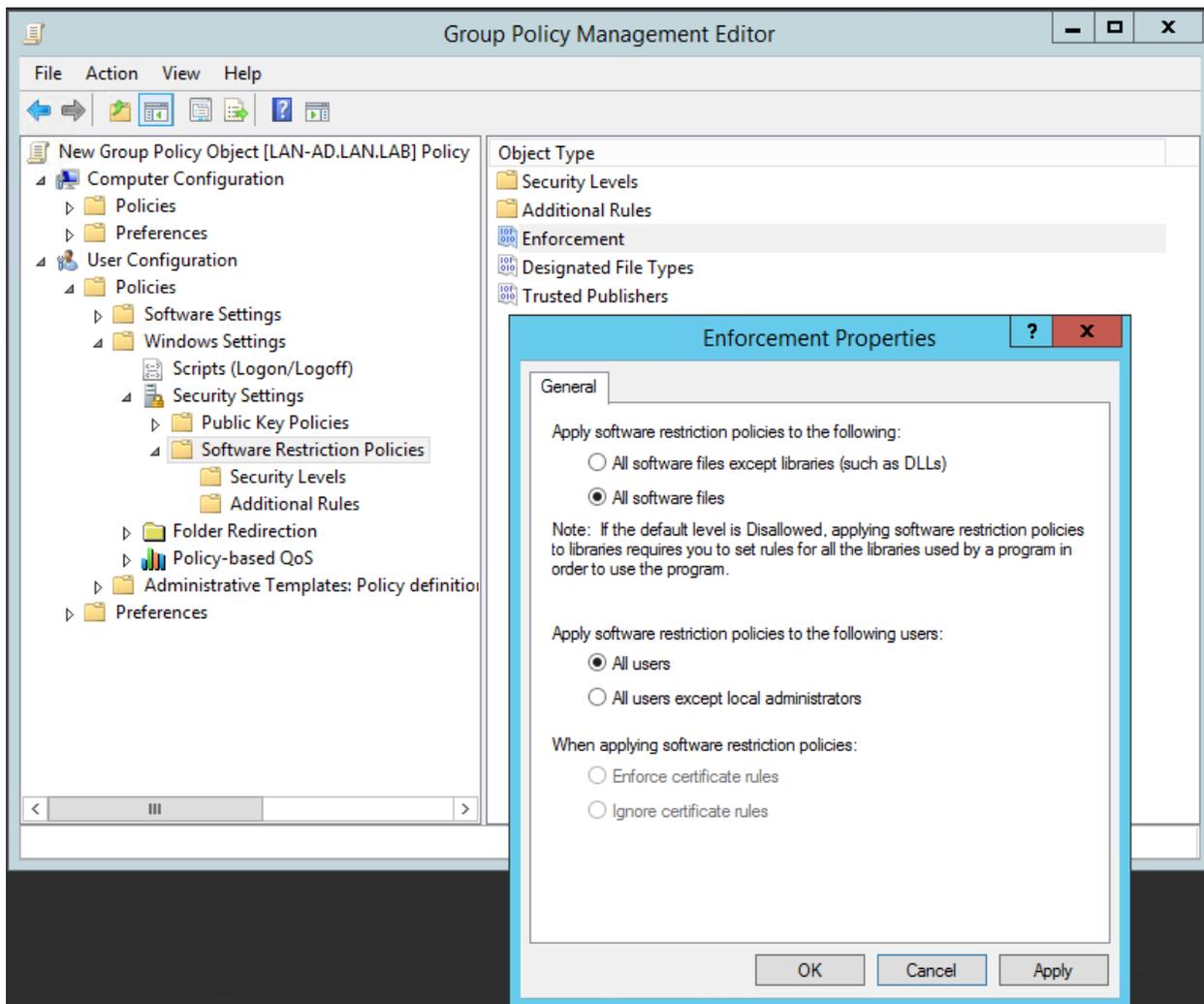
2174 Windows SRP is a feature of the Windows operating system and therefore did not require any specific
 2175 installation for use in the project.

2176 2.11.3 Configuration

2177 The Windows SRP configuration required setting GPOs on the AD servers to enable the policy on all
 2178 hosts that were part of the Windows domain. Additionally, hosts that were not part of the Windows
 2179 Domain had GPO settings configured locally to the host. Follow these steps to configure AD with user
 2180 accounts and set enforcement policies:

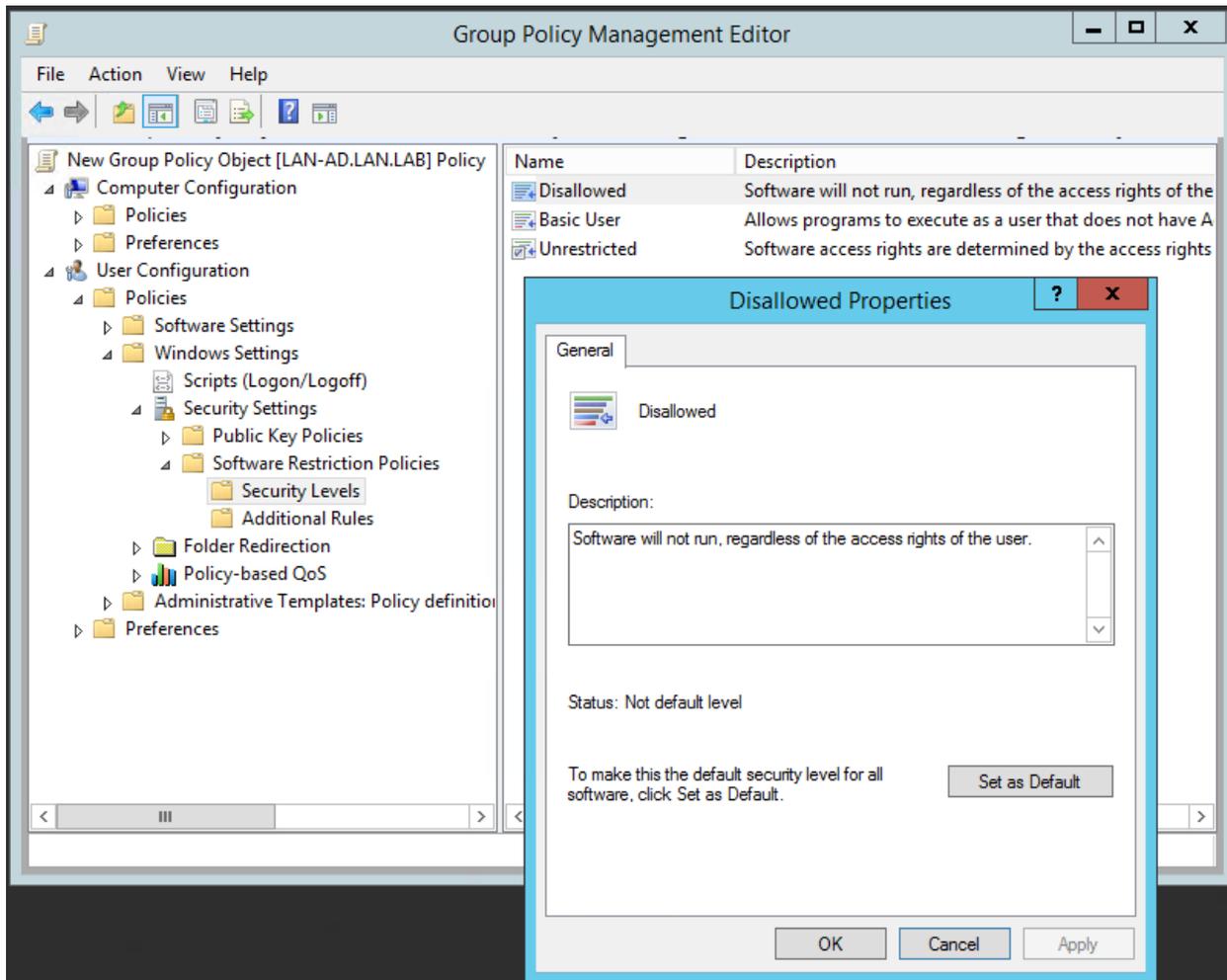
- 2181 1. Set up AD with a “Test User” OU and add the NCCOE User (nccoeUser) and Admin (nccoeAdmin)
2182 accounts for this project to the OU.
- 2183 2. To allow the NCCOE Admin account to be included as a local administrator within the
2184 environment, modify the Default Domain GPO to add Administrators to Restricted Group and
2185 include the NCCOE Admin account.
- 2186 3. To support applying GPOs as local settings to non-domain computers, download LGPO.zip from
2187 Microsoft Security Compliance Toolkit 1.0 available at [https://www.microsoft.com/en-](https://www.microsoft.com/en-us/download/details.aspx?id=55319)
2188 [us/download/details.aspx?id=55319](https://www.microsoft.com/en-us/download/details.aspx?id=55319).
- 2189 4. Review the National Security Agency (NSA) Guidance for Application Whitelisting using Software
2190 Restriction Policies and Guidelines for Application Whitelisting ICSs available at
2191 <https://apps.nsa.gov/iaarchive/library/reports/application-whitelisting-using-srp.cfm> and
2192 [https://apps.nsa.gov/iaarchive/library/ia-guidance/security-configuration/industrial-control-](https://apps.nsa.gov/iaarchive/library/ia-guidance/security-configuration/industrial-control-systems/guidelines-for-application-whitelisting-industrial-control-systems.cfm)
2193 [systems/guidelines-for-application-whitelisting-industrial-control-systems.cfm](https://apps.nsa.gov/iaarchive/library/ia-guidance/security-configuration/industrial-control-systems/guidelines-for-application-whitelisting-industrial-control-systems.cfm) respectively.
2194
- 2195 5. Create the Windows SRP GPO with the following settings:
- 2196 a. From the **Enforcement Properties** dialog (Figure 2-82):
- 2197 i. Select the **All Software Files** radio button.
- ii. Select the **All Users** radio button.

2198 Figure 2-82 Setting Enforcement Properties



- 2199
- 2200 b. In the Group Policy Management Editor, in the Security Levels folder:
- 2201 i. Double-click the Disallowed security level to open the Disallowed Properties window.
- 2202
- 2203 ii. Click the Set as Default radio button (Figure 2-83) to configure SRP in allowlist
- 2204 mode. After completing this step, only programs in the paths specified by the environment
- 2205 variables SYSTEMROOT (typically C:\Windows), PROGRAMFILES (C:\Program Files), and
- 2206 PROGRAMFILES(x86) (C:\Program Files (x86)) are permitted to execute. These path rules are
- 2207 automatically added when the "Disallowed" security level is set as the default.
- 2208

2209 Figure 2-83 Setting Security Level Default



2210

2211

2212

- c. Customize the Allowlist Rules to enhance security by disallowing specific subfolders in the default allowed paths and to support organization application requirements.

2213

2214

2215

2216

2217

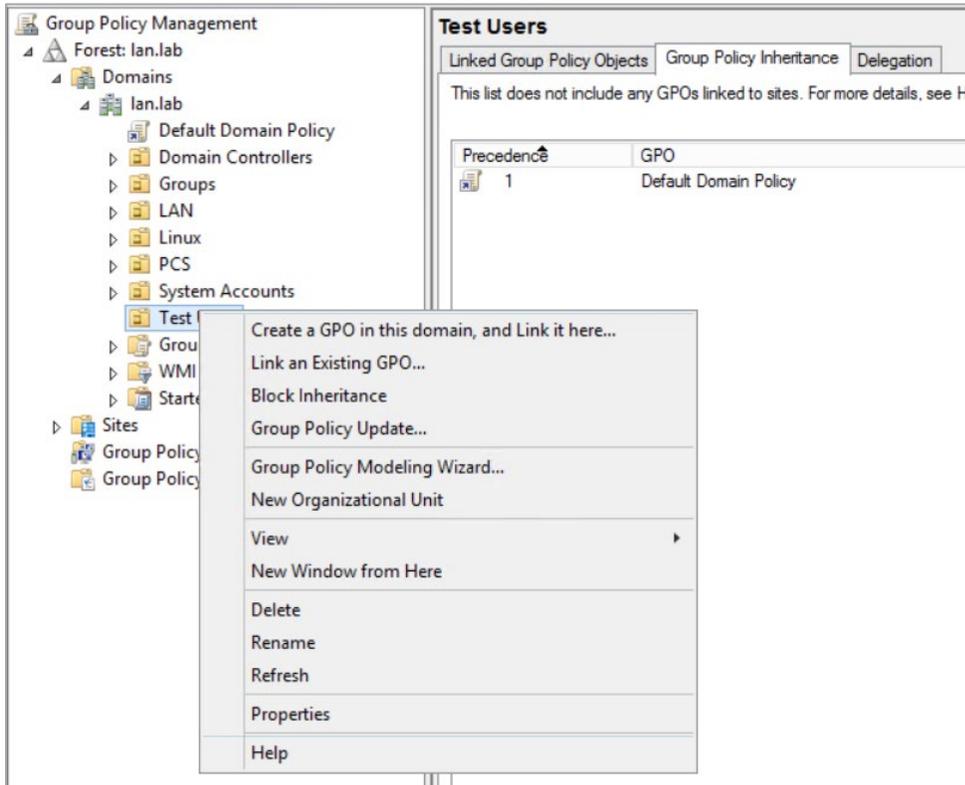
- i. Click the **Additional Rules** folder and apply the rules shown in Figure 2-84. This figure combines the NSA recommended path settings in addition to lab application requirements and for disabling installers and other executable content as indicated in the comments. *Organizations should audit their environments to determine the appropriate rules to define within the policy.*

2218 Figure 2-84 Additional Rules Defined for Lab Environment

Name	Type	Security Level	Description
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%	Path	Unrestricted	Default System Root Allow Rule
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\Debug	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\PCHEALTH\ERRORREP	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\Registration	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\catroot2	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\com\dmp	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\FixTmp	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\spool\drivers\c...	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\spool\PRINTERS	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\Tasks	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\System32\spool\SERVERS	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\SysWOW64\com\dmp	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\SysWOW64\FaxTmp	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\SysWOW64\Tasks	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\Tasks	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\Temp	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows NT\CurrentVersion\SystemRoot%\tracing	Path	Disallowed	Deny execution per NSA Guidance
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows\CurrentVersion\ProgramFilesDir (x86)%	Path	Unrestricted	Allow 32-bit Program Files on 64 bit systems.
%HKEY_LOCAL_MACHINE\SOFTWARE\Microsoft\Windows\CurrentVersion\ProgramFilesDir%	Path	Unrestricted	Default Program Files Directory Allow Rule
%USERPROFILE%\AppData\Local\Microsoft\OneDrive\OneDrive.exe	Path	Unrestricted	Temp rule for Workstations Allow OneDrive
%USERPROFILE%\ForeScout Console 8.2.1	Path	Unrestricted	Temporary Rule to Allow ForeScout Console
*.lnk	Path	Unrestricted	Allow Links to executables
*.msi	Path	Disallowed	Prevent installers from executing
\\.\%USERDNSDOMAIN%\Sysvol\	Path	Unrestricted	Allow Domain Login Scripts
C:\TwinCAT	Path	Unrestricted	Added to support CRS PLC Programming
E:\Program Files	Path	Unrestricted	Approved alternate Program Files Location
E:\Program Files (x86)	Path	Unrestricted	Approved alternate 32-bit Program Files location
runas.exe	Path	Disallowed	Deny execution per NSA Guidance

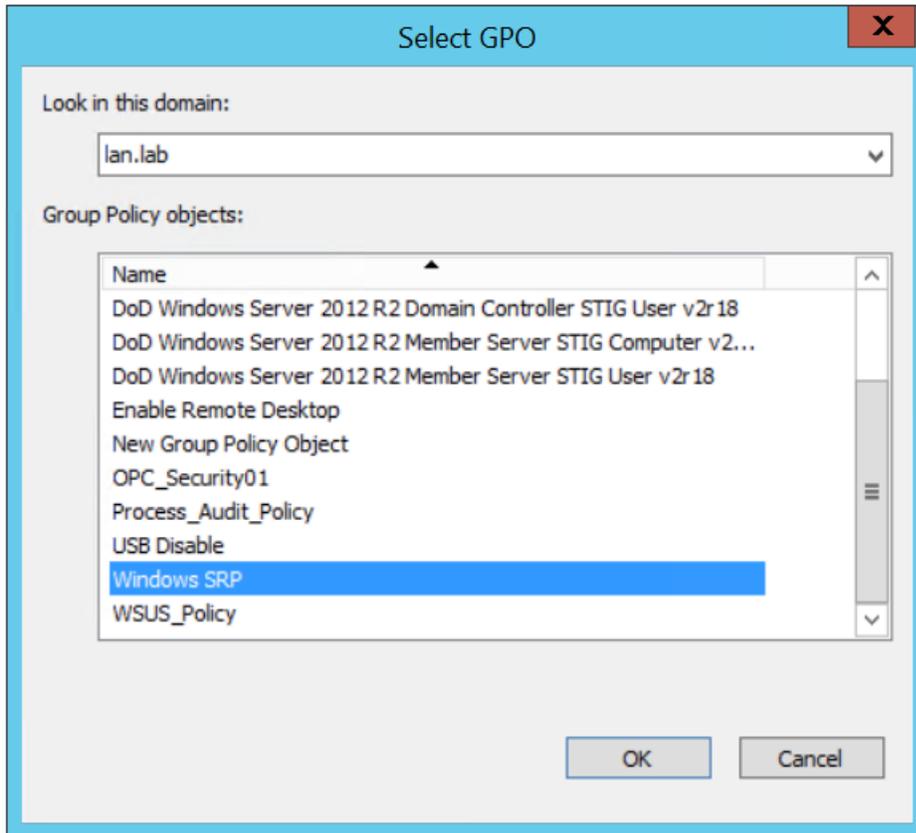
- 2219 6. Link the GPO to the Test User OU:
- 2220 a. In the Group Policy Management tool, right click the “Test User” OU and select **Link an**
- 2221 **Existing GPO** from the pop-up menu (Figure 2-85).

2222 Figure 2-85 Menu Options for Accessing the Link an Existing GPO Option



- 2223 b. In the dialog box, select the Windows SRP GPO Object from the list and click OK (Figure
2224 2-86).

2225 Figure 2-86 Dialog Box for Selecting GPO to Link



- 2226
- 2227 (Optional) Install GPO as the local policy on non-domain systems; for systems that are not joined
2228 to the domain, the nccoeUser and nccoeAdmin accounts are created as local user and
2229 administrator accounts, respectively. Additionally, the Windows SRP GPO is manually applied to
2230 the local system using the LGPO.exe application contained in the ZIP file from Step 3.

- 2231 c. Create a Backup of the Windows SRP GPO Object:
- 2232 i. From the Group Policy Manager, select the **Group Policy Objects** folder and right-
2233 click on the Windows SRP GPO object.
- 2234 ii. Select the **Back Up...** option from the pop-up menu.
- 2235 iii. In the dialog box, choose a destination location such as *C:\Backup GPO Folder* or
2236 some other convenient location to place the files and click **Back Up**.
- 2237 d. Copy the LGPO.exe along with the files created in the previous step to the non-domain
2238 computer system.
- 2239 e. Login as an administrator on the non-domain computer and navigate to the **{GUID}\Do-**
2240 **mainSysvol\GPO\User** folder, which should contain the **registry.pol** file for the GPO.

2241 f. Execute the following commands to apply the settings to the local nccoeUser and
2242 nccoeAdmin accounts:

2243 `lgpo.exe /u:nccoeUser registry.pol`

2244 `lgpo.exe /u:nccoeAdmin registry.pol`

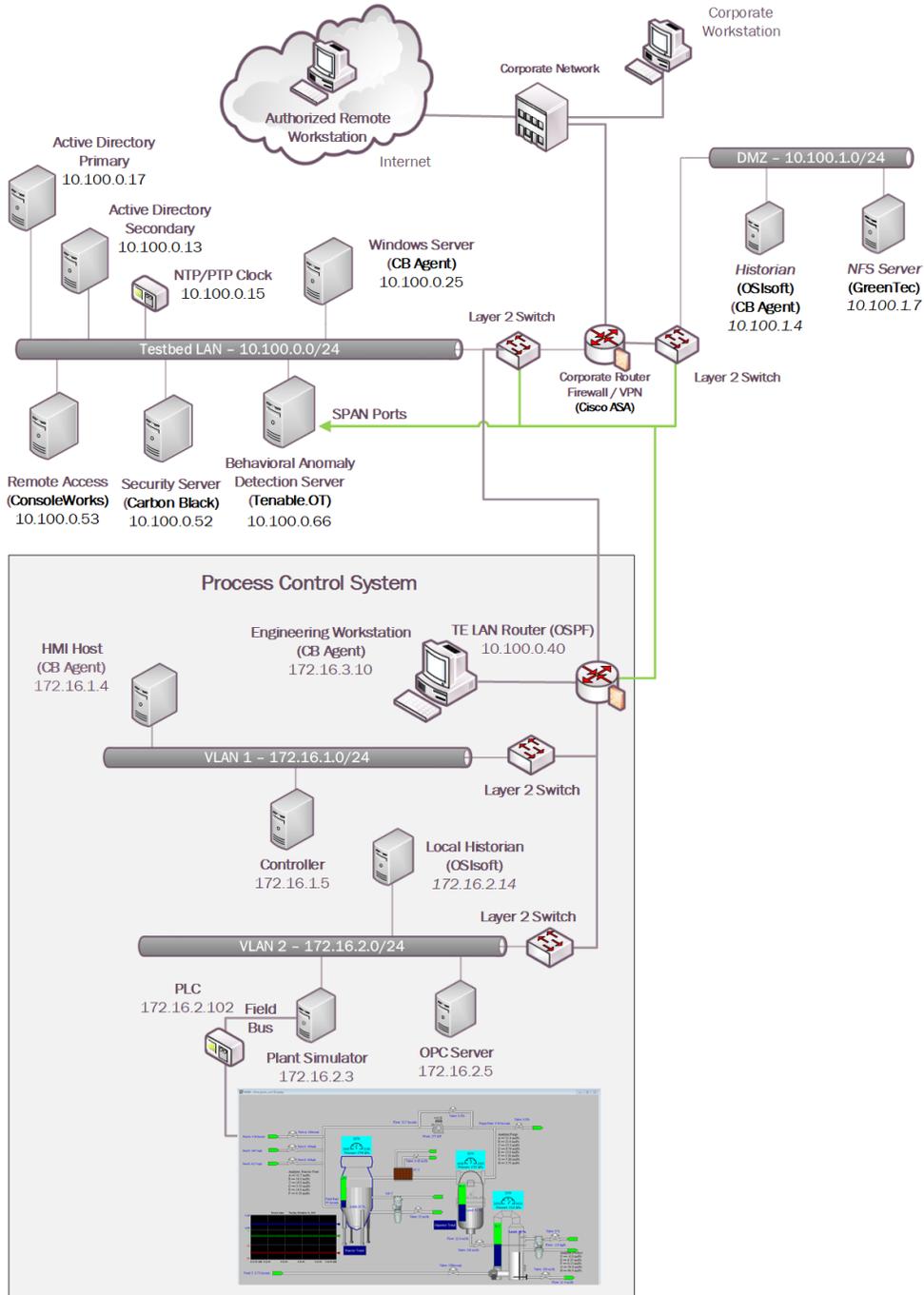
2245	Appendix A	List of Acronyms
2246	AAL	Application Allowlisting
2247	AD	Active Directory
2248	AF	Asset Framework
2249	BAD	Behavioral Anomaly Detection
2250	CRS	Collaborative Robotic System
2251	CRADA	Cooperative Research and Development Agreement
2252	CSF	NIST Cybersecurity Framework
2253	CSMS	Cybersecurity for Smart Manufacturing Systems
2254	DMZ	Demilitarized Zone
2255	DNAT	Destination Network Address Translation
2256	FOIA	Freedom of Information Act
2257	GPO	Group Policy Object
2258	HDD	Hard Disk Drive
2259	ICS	Industrial Control System
2260	IIS	Internet Information Services
2261	IoT	Internet of Things
2262	IT	Information Technology
2263	LAN	Local Area Network
2264	MFA	Multifactor Authentication
2265	MTD	Moving Target Defense
2266	NAT	Network Address Translation
2267	NCCoE	National Cybersecurity Center of Excellence
2268	NIST	National Institute of Standards and Technology
2269	NISTIR	NIST Interagency or Internal Report
2270	NSA	National Security Agency
2271	NTP	Network Time Protocol
2272	OT	Operational Technology

DRAFT

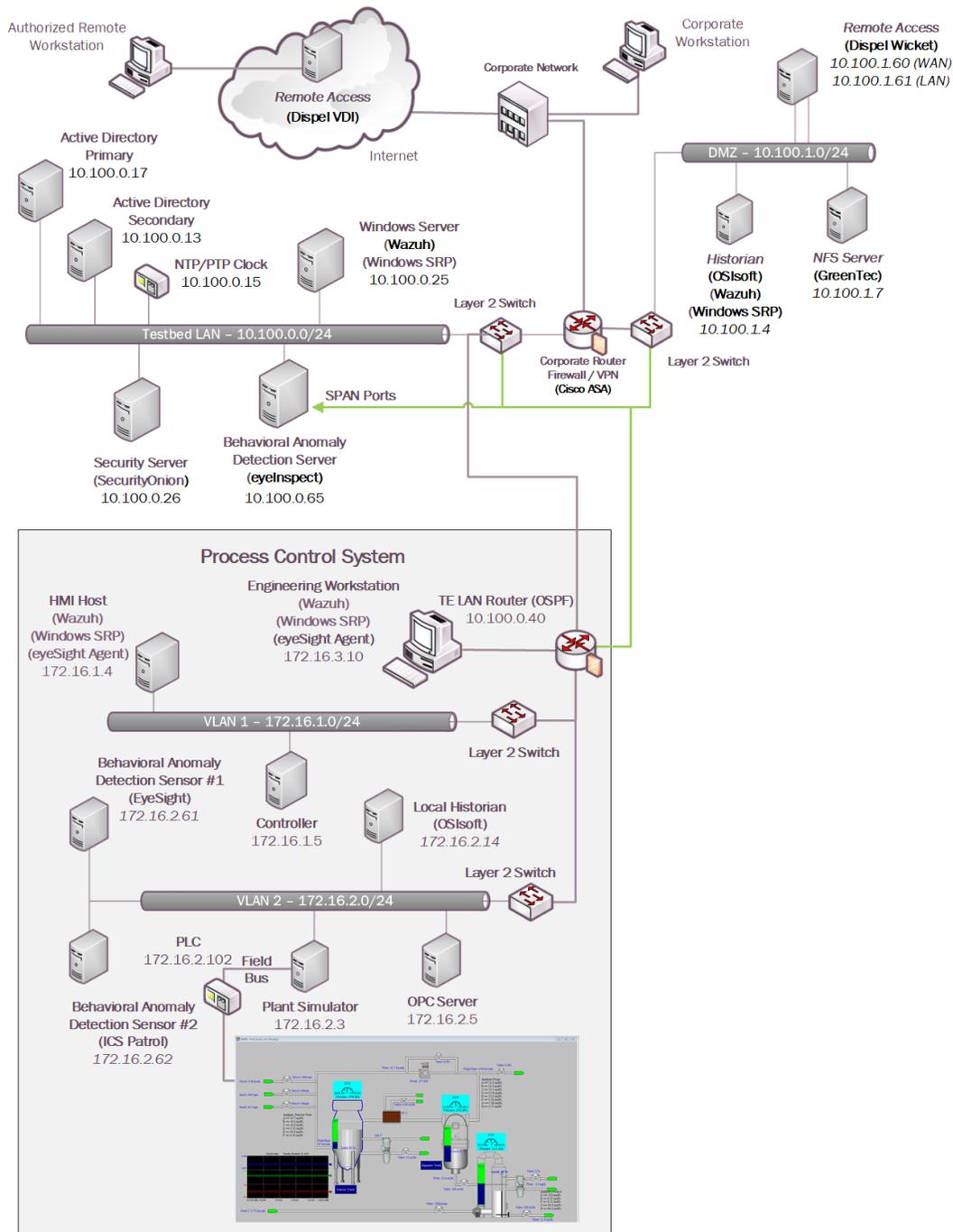
2273	OU	Organizational Unit
2274	PCS	Process Control System
2275	PI	Process Information
2276	PLC	Programmable Logic Controller
2277	RDP	Remote Desktop Protocol
2278	SP	Special Publication
2279	SPAN	Switch Port Analyzer
2280	VDI	Virtual Desktop Interface
2281	VLAN	Virtual Local Area Network
2282	VM	Virtual Machine
2283	VPN	Virtual Private Network

2284 Appendix B Build Architectures Diagrams

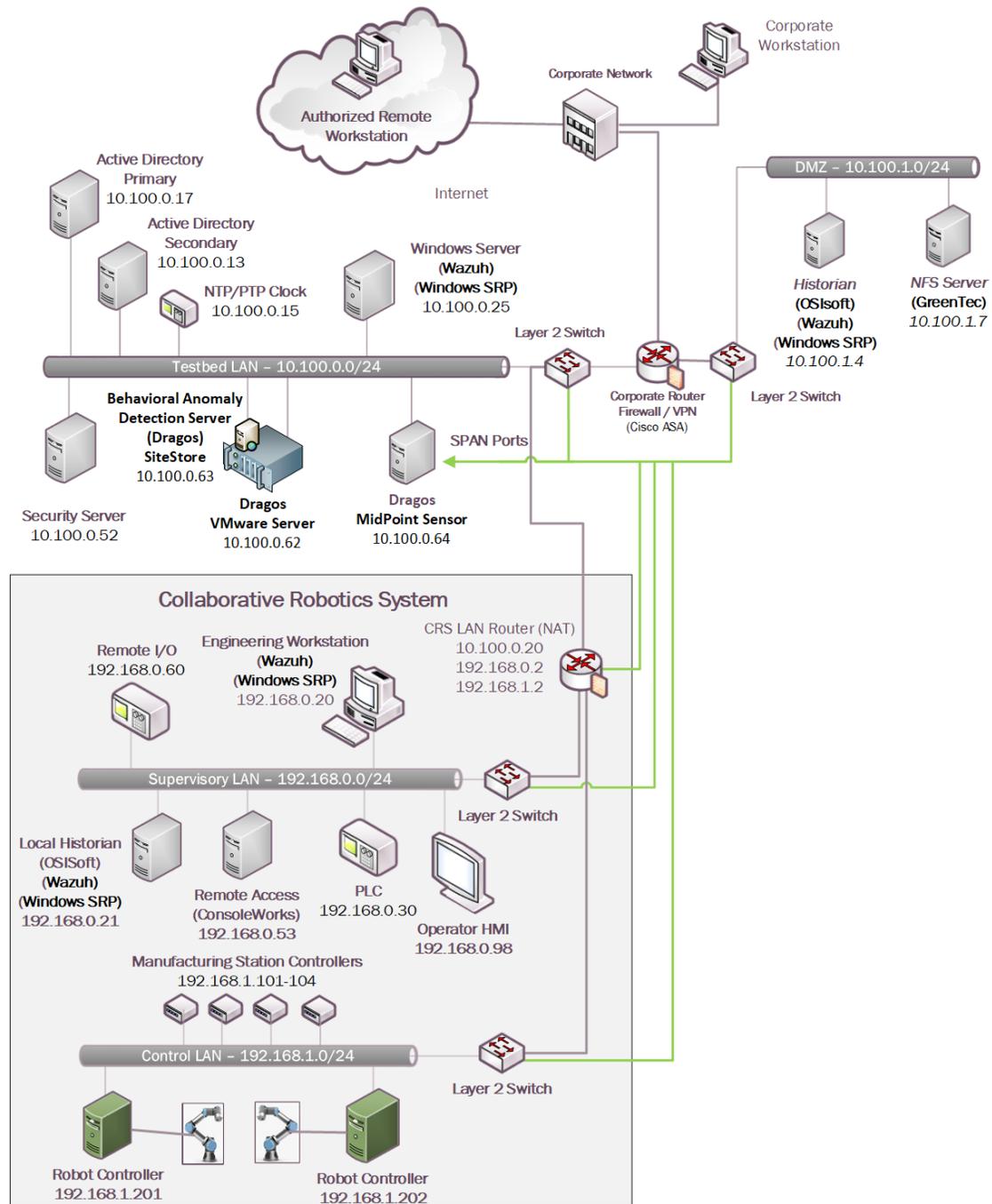
2285 Figure B-1 Build 1 Architecture Diagram



2286 Figure B-2 Build 2 Architecture Diagram



2287 Figure B-3 Build 3 Architecture Diagram



2288 Figure B-4 Build 4 Architecture Diagram

