PROJECT DESCRIPTION

SECURING PICTURE ARCHIVING AND COMMUNICATION SYSTEM (PACS)

Cybersecurity for the Healthcare Sector

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This document describes a cybersecurity challenge that is relevant across the healthcare sector. NCCoE cybersecurity experts will address this challenge through collaboration with members of the healthcare sector and vendors of cybersecurity solutions. The resulting reference design will detail an approach that can be used by Healthcare Delivery Organizations (HDOs).

ABSTRACT

Picture Archiving and Communication System (PACS) is defined by the Food and Drug Administration (FDA) as a Class II device that "provides one or more capabilities relating to the acceptance, transfer, display, storage, and digital processing of medical images. Its hardware components may include workstations, digitizers, communications devices, computers, video monitors, magnetic, optical disk, or other digital data storage devices, and hardcopy devices. The software components may provide functions for performing operations related to image manipulation, enhancement, compression or quantification." [1]

PACS is nearly ubiquitous in hospitals, prompting the Healthcare Sector Community of Interest to identify securing PACS as a critical need. PACS ties into doctor-patient workflow management, where results based on image interpretation determine patient next steps (e.g., determination of health condition, follow-on visits, patient care, and other actions). Therefore, PACS requires controls that provide significant integrity, availability, and confidentiality assurances.

PACS allows for remote image review, and generally has internet reachability. This exposes a threat vector that could act as a point where an attack may be performed or serve as a pivot point into an integrated healthcare information system.

The goal of this project is to provide a practical solution for securing the PACS ecosystem. The project team will perform a risk assessment, apply the NIST cybersecurity framework, provide guidance based on medical device standards and collaborate with industry and public partners. The result will be a freely available NIST

Cybersecurity Practice Guide that includes a reference design and a detailed description of practical steps needed to implement the solution based on standards and best practices.

KEYWORDS

Access control, auditing, authentication, authorization, DICOM, encryption, life cycle management, multifactor authentication, PACS, physical security, Picture Archiving and Communication System, PAM, Privileged Account Management, provisioning management, user analytics, Vendor Neutral Archive, VNA.

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Public comment period: *November 14, 2017 to December 14, 2017*

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1. Executive Summary

Purpose

Public feedback is being solicited for this draft document, which describes a National Cybersecurity Center of Excellence (NCCoE) project focused on securing the Picture Archiving and Communication System (PACS) in Healthcare Delivery Organizations (HDOs).

The purpose of this project is to provide guidance for securing the PACS ecosystem in HDOs and to include an example solution using existing, commercially and open source-available cybersecurity products.

PACS is defined by the Food and Drug Administration (FDA) as a Class II device that "provides one or more capabilities relating to the acceptance, transfer, display, storage, and digital processing of medical images. Its hardware components may include workstations, digitizers, communications devices, computers, video monitors, magnetic, optical disk, or other digital data storage devices, and hardcopy devices. The software components may provide functions for performing operations related to image manipulation, enhancement, compression or quantification." [1]

PACS is nearly ubiquitous in hospitals, prompting the Healthcare Sector to identify securing PACS as a critical need. PACS ties into doctor-patient workflow management, where results based on image interpretation determine patient next steps (e.g., determination of health condition, follow-on visits, patient care, and other actions). Therefore, PACS requires controls that provide significant integrity, availability, and confidentiality assurances.

Compromises on PACS could result in significant data loss, serve as an avenue to cause disruption throughout a hospital's system, or, should information be altered or misdirected, may impede timely diagnosis and treatment. There may also be interfaces into billing systems, which could disrupt billing processes for hospitals. As healthcare organizations become more attractive targets for malicious actors, the need to improve these organizations' cybersecurity capabilities is paramount.

Many HDOs face challenges securing a PACS. These challenges include:

- controlling and monitoring (and auditing) HDO user accounts
- controlling and monitoring (and auditing) access by users external to the HDO
- enforcing least privilege and separation of duties policies for all (internal and external) users
- securing and monitoring connections to the HDO ecosystem
- securing and monitoring connections to and from systems external to the HDO

The publication of this draft Project Description is the beginning of a process that will identify project collaborators, as well as standards-based, commercially and open

source-available hardware and software components. These products will be integrated and implemented in a laboratory environment to build open, standards-based, modular, end-to-end reference designs that will address the security challenges of a PACS ecosystem. The approach includes an architectural definition, logical design, build development, security analysis, test and evaluation, security control mapping, and future build considerations. The output of the process will be the publication of a multi-volume NIST Cybersecurity Practice Guide that will help healthcare sector organizations implement more secure PACS solutions through the use of stronger security controls.

The project will use NIST SP 800-160, Systems Security Engineering, to develop an example solution for securing PACS and will incorporate the principles of systems security engineering, along with associated activities (i.e., techniques, methods, and practices), into the Practice Guide to ensure that when used by the targeted audience, the protection needs of stakeholders (i.e., the HDOs) are addressed with the appropriate fidelity and rigor across the entire life cycle of a PACS implementation.

The Practice Guide will include the definition of organizational personnel roles and responsibilities. The project will use the National Initiative for Cybersecurity Education (NICE) Cybersecurity Workforce Framework (SP 800-181) to:

- develop cybersecurity roles and responsibilities applicable to PACS in small, medium, and large HDO environments as well as in individual medical offices, and
- specify the knowledge, skills, and abilities required of these defined roles

Scope

The scope of the project will include the PACS ecosystem to allow storage, retrieval, management, distribution, and presentation of medical images. The resulting example solution will include implementation of:

- PACS Server and Archive
- PACS workstation / DICOM viewer
- Vendor Neutral Archive (VNA)
- Electronic Health Record / Electronic Medical Record (EHR/EMR) system cloud services
- users with permission to view images
- users with permission to add data to images' activity logging (textual and video)
- typical administrative users

Assumptions

The example solution will use PACS and other components to provide increased security benefits while minimizing impacts to availability. The NCCoE assumes that organizations

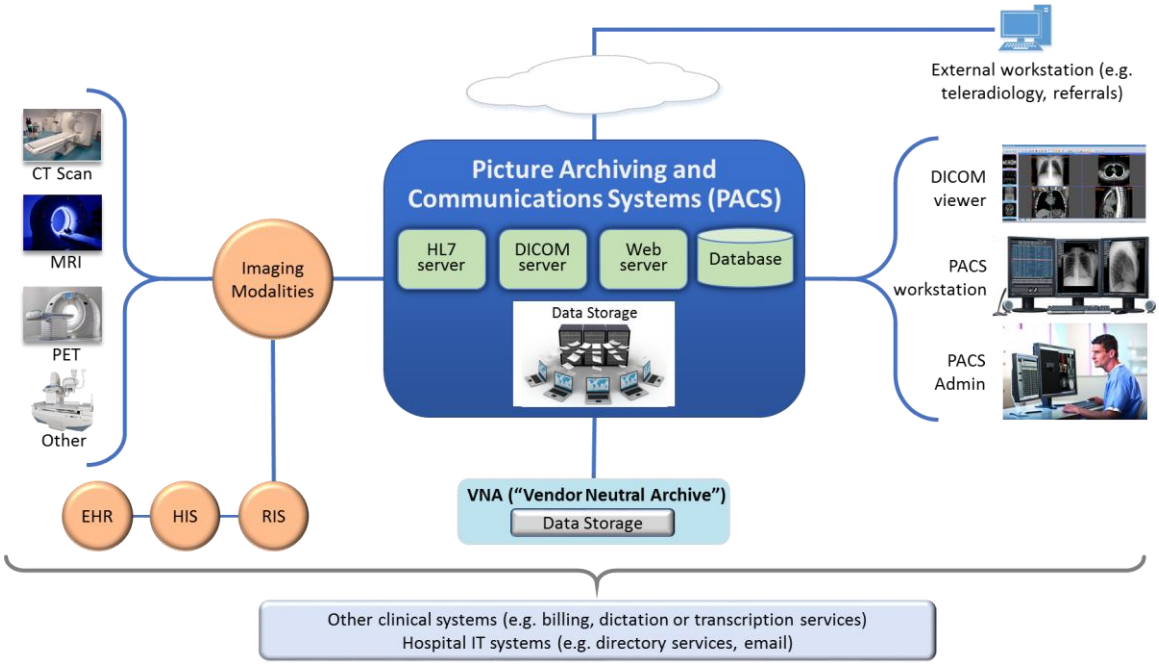
will perform a risk assessment to determine the risk reduction value of an investment in one or more of the PACS capabilities included in the reference architecture.

A key assumption is that all potential adopters of this project or any of its components have polices describing the separation of duties and least privilege for administrative/privileged users.

2. High-Level Architecture

Figure 1 shows the high-level architecture diagram of a generic PACS ecosystem. The reference architecture addresses the scope as noted in Section 1 and the desired characteristics noted below.

Figure 1: High-Level Architecture



Component List

The NCCoE has a dedicated lab environment for hosting development of the example solution, including the following features:

- network with machines using a directory service
- virtualization servers
- network switches
- remote access solution with Wi-Fi and virtual private network (VPN)

Collaboration partners (participating vendors) will need to provide specialized components and capabilities to realize this solution including, but not limited to:

- PACS Servers, special applications, and workstations
- VNA
- data storage
- modality or modality simulator
- radiology information system (RIS) or RIS simulator
- notification system
- EHR/EMR
- certificate management
- authentication mechanism
- data encryption
- endpoint protection
- logging, monitoring, security information and event management (SIEM)
- network infrastructure controls
- asset management

Desired Security Characteristics

The security capabilities, behaviors, and life cycle security requirements of the solution are identified in the list below. Security Capabilities and Behaviors and Life Cycle Security are two of the major design principles described in [2].

PACS is a core component in the medical imaging ecosystem that involves maintaining clinical images used for patient encounter diagnostics and medical history archival. The intent in devising appropriate security measures is to increase security assurance across the HDO enterprise.

The controls foundation to be implemented is rooted in the NIST Risk Management Framework, and incorporates elements from Federal Information Processing Standard (FIPS) 199/NIST 800-60, 800-53, 800-34, and Integrating the Healthcare Enterprise (IHE) practices. The primary security functions and processes to be implemented for this project are:

Asset Management – includes identification of assets on network and management of assets to be deployed to workstations

Risk Assessment – includes risk management strategy

Access Control – includes user account management, remote access

- controlling (and auditing) user accounts
- controlling (and auditing) access by external users
- enforcing least privilege for all (internal and external) users
- enforcing separation of duties policies

    - Privileged Access Management (PAM) with emphasis on segregation of duties
- enforcing least functionality

User Identification and Authentication

- multifactor authentication for the system that aligns with the sensitive information and function that PACS performs
- viable federated identity management
- credential management

Data Security – includes data availability

- securing and monitoring storage of data – includes data encryption (for data at rest)
    - Data at rest controls should implement some form of a data security manager that would allow for policy application to encrypted data, inclusive of access control policy
- securing the distribution of data—includes data encryption (for data in transit) and data loss prevention
- Controls that promote data integrity

Information Protection Processes and Procedures – includes data backup, endpoint protection for workstations

Maintenance – local and remote maintenance

Protective Technology – host-based intrusion prevention, solutions for malware (malicious code detection), audit logging, (automated) audit log review and physical protection

Anomalies and Events – analysis of detected events (from logs, monitoring results, SIEM)

- Centralized mechanism to capture and analyze system and network events

Security Continuous Monitoring – monitoring for unauthorized personnel, devices, software, connections

- vulnerability management -- includes vulnerability scanning and remediation
- patch management
- system configuration security settings
- user account usage (local and remote) and user behavioral analytics

Communications – communications and control networks are protected (e.g., firewall, network access control, network infrastructure controls)

- securing and monitoring connections within the HDO ecosystem
    - network segmentation
- securing and monitoring connections to and from external systems

Response Planning – response plan executed after an event, mitigation of security issues

Recovery and Restoration – recovery and restoration activities executed after an event

- business continuity and business resumption processes
    - In addition to restoration capability from archival media, the project should consider high availability and continuity for data storage. Implicitly, disk arrays used for image storage should have the capability to implement various Redundant Array of Independent Disks (RAID) configurations. RAID 0, 1, 5, 6, and 1+0 should be supported. Disk arrays should also be made available for cold or warm restore/failover capability.

3. SCENARIOS

The following scenarios have been used to develop this project description. IHE Radiology Profiles were referenced for some of the scenarios. [3] They will become the use cases for design of the reference architecture. Most scenarios emphasize supporting typical workflow or use case for using the PACS and the medical imaging ecosystem. While the reference architecture needs to ensure that the normal workflow/data flow can accommodate all necessary steps for completing the task, it is important to realize that the reference architecture also needs to ensure that relevant cybersecurity concerns are being addressed for each scenario.

Scenario 1: Sample Radiology Practice Workflows

This scenario covers a few basic workflows

- radiology exam for a patient
- post-process images by healthcare professionals
- interpret images and reporting by healthcare professionals

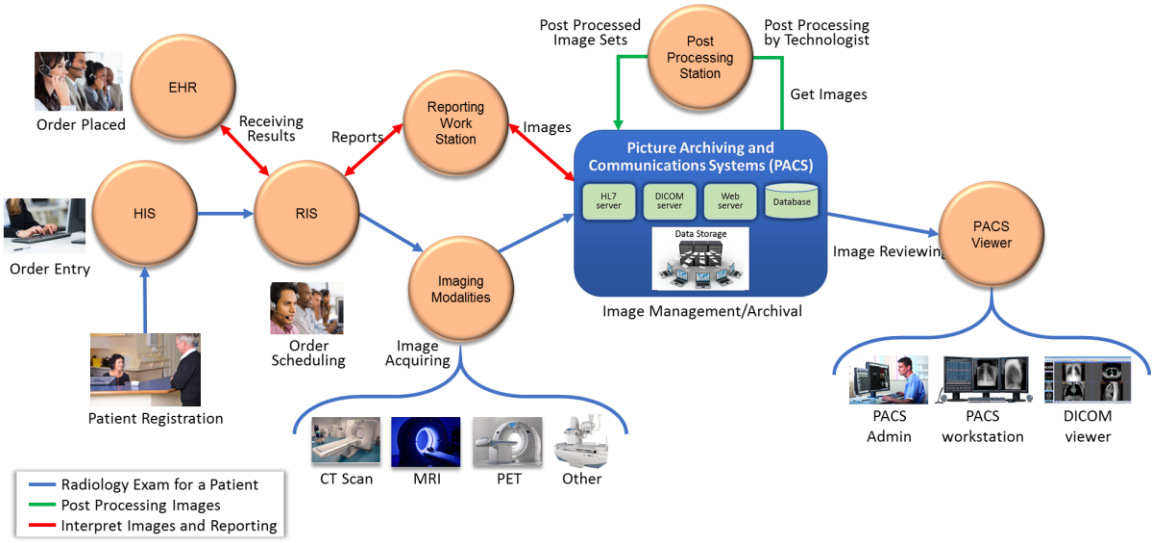
Radiology Exam for a Patient: This workflow considers a common patient encounter, wherein a patient may be registered within the care provider's systems and a physician requests an image. The patient is scheduled for the imaging activity, the image is acquired, and then is routed to a system for storage, viewing and review, and subsequent archival as part of the patient's medical history.

Post-processing Images: This workflow may involve imaging technologists who may update or monitor procedure status and capture statistical information pertaining to the image, and generate annotations that are then pushed to the PACS for subsequent workflow triage.

Interpret Images and Reporting: Once the image post-processing is done, healthcare professionals perform analysis, interpretation, and diagnosis with annotations that are pushed to PACS for reporting.

The workflows are depicted in Figure 2 below.

Figure 2: Sample Radiology Practice Workflows



Note: For purposes of the NCCoE lab environment, several components would be simulated, rather than deployment and use of actual equipment. Examples of the use of simulators would be imaging modalities, where the intent would be to generate digital imaging and communication in medicine (DICOM) and non-DICOM images that are analogous to data that is generated by those devices, short of implementing medical imaging equipment, given that actual deployment may be impractical.

Cybersecurity concerns are:

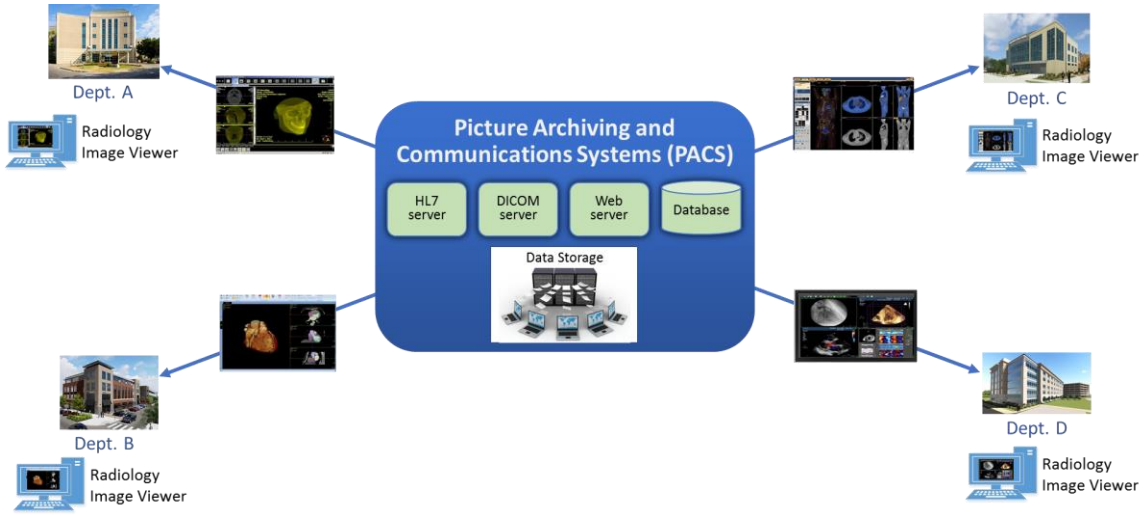
- asset management
- risk assessment
- access control
- user identification and authentication
- data security
- information protection processes and procedures
- maintenance
- protective technology
- anomalies and events
- security continuous monitoring
- communications
- response planning
- recovery and restoration

Scenario 2: Access to Aggregations and Collections of Different Types of Images

A collection of medical images and related reports can be aggregated, archived, and accessed by multiple departments with the hospital, such as pathology, surgery, and

oncology. The scenario considers the Radiology PACS as central and authoritative for cross-departmental imaging. The display function provides consolidated access to additional clinically relevant data from other archives (such as the Cardiology PACS, long-term archive, etc.).

Figure 3: Access to Aggregations and Collections of Different Types of Images



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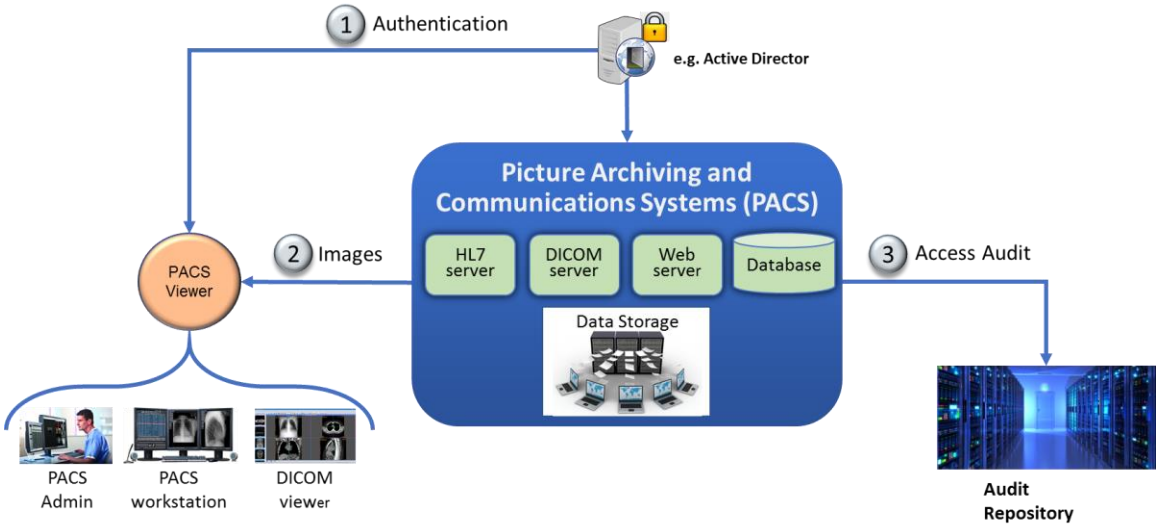
Scenario 3: Accessing, Monitoring, and Auditing

This scenario ensures a consolidated audit events trail on user activity across several imaging and information systems throughout the enterprise systems that are interconnected in a secure manner.

253 **Figure 4: Accessing, Monitoring, and Auditing**



254

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256 • access control
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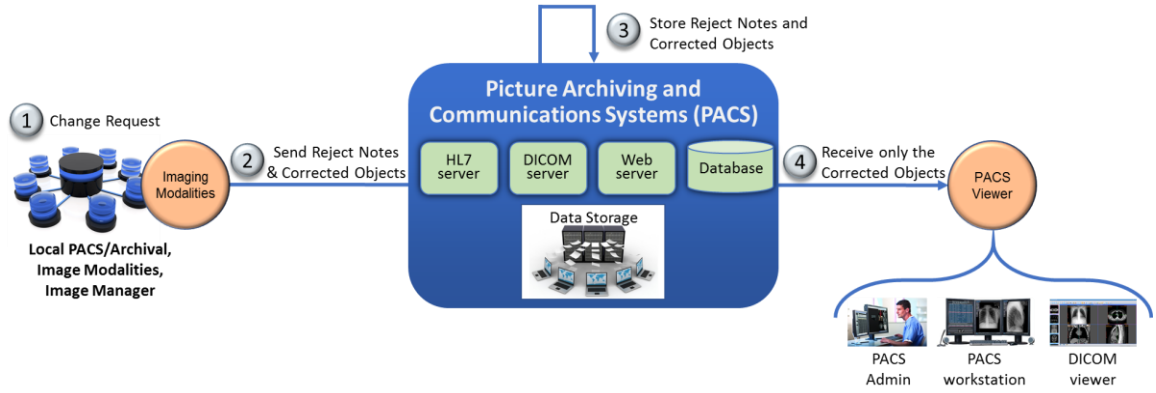
260 • protective technology
261 • anomalies and events
262 • security continuous monitoring
263 • communications

264 **Scenario 4: Imaging Object Change Management**

265 This scenario supports the changes that include (1) object rejection due to quality or
266 patient safety reasons, (2) correction of incorrect modality worklist entry selection, and
267 (3) expiration of objects due to data retention requirements. It defines how changes are
268 captured and how to communicate these changes. The scenario considers those actions
269 when an authorized healthcare professional, upon review of the image, determines that
270 errors or qualitative defect found in an image may lead to an inappropriate conclusion.

The reference architecture needs to ensure that only authorized imaging changes are allowed.

Figure 5: Imaging Object Change Management



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- communications
- response planning
- recovery and restoration

4. Relevant Standards and Guidance

General Cybersecurity and Risk Management

- NIST Cybersecurity Framework
  http://www.nist.gov/itl/cyberframework.cfm

- NIST SP 800-53 Rev. 4, Security and Privacy Controls for Federal Information Systems and Organizations
  http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-53r4.pdf

- NIST SP 800-39, Managing Information Security Risk Organization, Mission, and Information System View
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-39.pdf

- NIST SP 800-37 Rev1, Guide for Applying the Risk Management Framework to Federal Information Systems: A Security Life Cycle Approach
  http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-37r1.pdf

- NIST SP 800-30 Rev1, Guide for Conducting Risk Assessments
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-30r1.pdf

- ANSI/AAMI)/IEC 80001-1:2010, Application of risk management for IT Networks incorporating medical devices – Part 1: Roles, responsibilities and activities

- IEC Technical Report (TR) 80001-2-1, Edition 1.0 2012-07, Technical Report, Application of risk management for IT-networks incorporating medical devices – Part 2-1: Step-by-step risk management of medical IT-networks – Practical applications and examples

- IEC TR 80001-2-2, Edition 1.0 2012-07, Technical Report, Application of risk management for IT Networks incorporating medical devices – Part 2-2: Guidance for the disclosure and communication of medical device security needs, risks and controls

- AAMI TIR57, Principles for medical device security – risk management

Cybersecurity / Technology-Related Standards

- NIST SP 800-77, Guide to IPsec VPNs
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-77.pdf

- NIST SP 800-52 Rev 1, Guidelines for the Selection, Configuration, and Use of Transport Layer Security (TLS) Implementations
  http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-52r1.pdf

- Internet Engineering Task Force (IETF) Request for Comments (RFC) 4301, Security Architecture for the Internet Protocol
  https://tools.ietf.org/html/rfc4301

- NIST SP 800-41 Rev 1, Guidelines on Firewalls and Firewall Policy
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-41r1.pdf

- NIST SP 800-95, Guide to Secure Web Services
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-95.pdf

- NIST Federal Information Processing Standards (FIPS) 140-2, Security Requirements for Cryptographic Modules
  https://csrc.nist.gov/publications/detail/fips/140/2/final

- NIST Special Publication SP 800-57 Part 1 Revision 4 - Recommendation for Key Management: Part 1 – General
  http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-57pt1r4.pdf

- Special Publication 800-144, Guidelines on Security and Privacy in Public Cloud Computing
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-144.pdf

- Special Publication 800-146, Cloud Computing Synopsis and Recommendations
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-146.pdf

Other Relevant Regulations, Standards, and Guidance (Healthcare / Medical Devices)

- FDA, Content of Premarket Submissions for Management of Cybersecurity in Medical Devices - Guidance for Industry and Food and Drug Administration Staff, Document Issued on: October 2, 2014
  https://www.fda.gov/downloads/medicaldevices/deviceregulationandguidance/guidancedocuments/ucm356190.pdf

- FDA, Postmarket Management of Cybersecurity in Medical Devices - Guidance for Industry and Food and Drug Administration Staff, Document Issued on: December 28, 2016
  https://www.fda.gov/ucm/groups/fdagov-public/@fdagov-meddev-gen/documents/document/ucm482022.pdf

- FDA, Guidance for Industry - Cybersecurity for Networked Medical Devices Containing Off-the-Shelf (OTS) Software
  http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-175b.pdf

- FDA, Guidance for Submission of Premarket Notifications for Medical Image Management Devices
  https://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm073721.pdf

- FDA, Medical Device Data Systems, Medical Image Storage Devices, and Medical Image Communications Device
  https://www.fda.gov/downloads/medicaldevices/deviceregulationandguidance/guidancedocuments/ucm401996.pdf

- NIST SP 800-66, An Introductory Resource Guide for Implementing the Health Insurance Portability and Accountability Act (HIPAA) Security Rule
  http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-66r1.pdf

- DHHS Office for Civil Rights, HIPAA Security Rule Crosswalk to NIST Cybersecurity Framework
  https://www.hhs.gov/sites/default/files/nist-csf-to-hipaa-security-rule-crosswalk-02-22-2016-final.pdf

- Department of Homeland Security (DHS), Attack Surface: Healthcare and Public Health Sector
  https://info.publicintelligence.net/NCCIC-MedicalDevices.pdf

- IHE Radiology (RAD) Technical Framework
  http://www.ihe.net/Technical_Frameworks/#radiology

- Digital Imaging and Communications in Medicine (DICOM) – wiki
  https://en.wikipedia.org/wiki/DICOM

- ISO 12052:2011 "Health informatics -- Digital imaging and communication in medicine (DICOM) including workflow and data management"

5. Security Control Map

Table 1 maps the characteristics of commercial and open source products that the NCCoE will apply to this cybersecurity challenge to the applicable standards and best practices described in the Framework for Improving Critical Infrastructure Cybersecurity (CSF), and the Healthcare Sector specific standards and guidance such as International Electrotechnical Commission Technical Report (IEC TR) 80001-2-2, Health Insurance Portability and Accountability Act (HIPAA) and International Standards Organization / International electrotechnical Commission (ISO/IEC) 27001. This exercise is meant to demonstrate the real-world applicability of standards and best practices, but does not imply that products with these characteristics will meet your industry's requirements for regulatory approval or accreditation.

413 **Table 1: Security Control Map**

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
IDENTIFY (ID)	Asset Management (ID.AM)	ID.AM-1: Physical devices and systems within the organization are inventoried	CM-8	N/A	C.F.R. §§ 164.308(a)(1)(ii)(A), 164.310(a)(2)(ii), 164.310(d)	A.8.1.1, A.8.1.2
		ID.AM-5: Resources (e.g., hardware, devices, data, time, and software) are prioritized based on their classification, criticality, and business value	CP-2, RA-2, SA-14	DTBK	C.F.R. § 164.308(a)(7)(ii)(E)	A.8.2.1
	Risk Assessment (ID.RA)	ID.RA-1: Asset vulnerabilities are identified and documented	CA-2, CA-7, CA-8, RA-3, RA-5, SA-5, SA-11, SI-2, SI-4, SI-5	RDMP	C.F.R. §§ 164.308(a)(1)(ii)(A), 164.308(a)(7)(ii)(E), 164.308(a)(8), 164.310(a)(1), 164.312(a)(1), 164.316(b)(2)(iii)	A.12.6.1, A.18.2.3
		ID.RA-4: Potential business impacts and likelihoods are identified	RA-2, RA-3, PM-9, PM-11, SA-14	SAHD, SGUD	C.F.R. §§ 164.308(a)(1)(i), 164.308(a)(1)(ii)(A), 164.308(a)(1)(ii)(B), 164.308(a)(6), 164.308(a)(7)(ii)(E), 164.308(a)(8), 164.316(a)	A.12.6.1, A.18.2.3

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
		ID.RA-5: Threats, vulnerabilities, likelihoods, and impacts are used to determine risk	RA-2, RA-3, PM-16	SGUD	C.F.R. §§ 164.308(a)(1)(ii)(A), 164.308(a)(1)(ii)(B), 164.308(a)(1)(ii)(D), 164.308(a)(7)(ii)(D), 164.308(a)(7)(ii)(E), 164.316(a)	none
		ID.RA-6: Risk responses are identified and prioritized	PM-4, PM-9	DTBK , SGUD	C.F.R. §§ 164.308(a)(1)(ii)(B), 164.314(a)(2)(i)(C), 164.314(b)(2)(iv)	none
PROTECT (PR)	Identity Management and Access Control (PR.AC)	(note: not directly mapped in CSF)	AC-1, AC-11, AC-12	ALOF		
		PR.AC-1: Identities and credentials are issued, managed, revoked, and audited for authorized devices, users, and processes	AC-2, IA Family	AUTH, CNFS, EMRG, PAUT	C.F.R. §§ 164.308(a)(3)(ii)(B), 164.308(a)(3)(ii)(C), 164.308(a)(4)(i), 164.308(a)(4)(ii)(B), 164.308(a)(4)(ii)(C), 164.312(a)(2)(i), 164.312(a)(2)(ii), 164.312(a)(2)(iii), 164.312(d)	A.9.2.1, A.9.2.2, A.9.2.4, A.9.3.1, A.9.4.2, A.9.4.3
		PR.AC-2: Physical access to assets is managed and protected	PE-2, PE-3, PE-4, PE-5, PE-6, PE-9	PLOK, TXCF, TXIG	C.F.R. §§ 164.308(a)(1)(ii)(B), 164.308(a)(7)(i), 164.308(a)(7)(ii)(A), 164.310(a)(1), 164.310(a)(2)(i), 164.310(a)(2)(ii), 164.310(a)(2)(iii),	A.11.1.1, A.11.1.2, A.11.1.4, A.11.1.6, A.11.2.3

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Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
					164.310(b), 164.310(c), 164.310(d)(1), 164.310(d)(2)(iii)	
		PR.AC-3: Remote access is managed	AC-17, AC-19, AC-20	NAUT, PAUT	C.F.R. §§ 164.308(a)(4)(i), 164.308(b)(1), 164.308(b)(3), 164.310(b), 164.312(e)(1), 164.312(e)(2)(ii)	A.6.2.2, A.13.1.1, A.13.2.1
		PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties	AC-2, AC-3, AC-5, AC-6, AC-16	AUTH, CNFS, EMRG, NAUT, PAUT	C.F.R. §§ 164.308(a)(3), 164.308(a)(4), 164.310(a)(2)(iii), 164.310(b), 164.312(a)(1), 164.312(a)(2)(i), 164.312(a)(2)(ii)	A.6.1.2, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4
		PR.AC-5: Network integrity is protected, incorporating network segregation where appropriate	AC-4, SC-7	NAUT	C.F.R. §§ 164.308(a)(4)(ii)(B), 164.310(a)(1), 164.310(b), 164.312(a)(1), 164.312(b), 164.312(c), 164.312€	A.13.1.1, A.13.1.3, A.13.2.1
		PR.AC-6: Identities are proofed and bound to credentials, and asserted in interactions when appropriate	AC-2, AC-3, AC-5, AC-6, AC-16, AC-19, AC-24, IA-2, IA-4, IA-5, IA-8, PE-2, PS-3	AUTH , CNFS, EMRG, NAUT, PLOK , SGUD,	not available	A.6.1.2, A.7.1.1, A.9.1.2, A.9.2.2, A.9.2.3, A.9.2.5, A.9.2.6, A.9.4.1, A.9.4.4
	Data Security (PR.DS)	PR.DS-1: Data-at-rest is protected	SC-28	IGAU, STCF	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(b)(1), 164.310(d), 164.312(a)(1), 164.312(a)(2)(iii), 164.312(a)(2)(iv),	A.8.2.3

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	Category	Subcategory	SP800-53R4	IEC TR 80001-2-2	HIPAA Security Rule 45	ISO/IEC 27001
					164.312(b), 164.312(c), 164.314(b)(2)(i), 164.312(d)	
		PR.DS-2: Data-in-transit is protected	SC-8	IGAU, TXCF	C.F.R. §§ 164.308(b)(1), 164.308(b)(2), 164.312(e)(1), 164.312(e)(2)(i), 164.312(e)(2)(ii), 164.314(b)(2)(i)	A.8.2.3, A.13.1.1, A.13.2.1, A.13.2.3, A.14.1.2, A.14.1.3
		PR.DS-3: Assets are formally managed throughout removal, transfers, and disposition	CM-8, MP-6, PE-16		C.F.R. §§ 164.308(a)(1)(ii)(A), 164.310(a)(2)(ii), 164.310(a)(2)(iii), 164.310(a)(2)(iv), 164.310(d)(1), 164.310(d)(2)	A.12.3.1
		PR.DS-4: Adequate capacity to ensure availability is maintained	AU-4, CP-2, SC-5	AUDT, DTBK	C.F.R. §§ 164.308(a)(1)(ii)(A), 164.308(a)(1)(ii)(B), 164.308(a)(7), 164.310(a)(2)(i), 164.310(d)(2)(iv), 164.312(a)(2)(ii)	A.12.3.1
		PR.DS-5: Protections against data leaks are implemented	AC-4, AC-5, AC-6, PE-19, PS-3, PS-6, SC-7, SC-8, SC-13, SC-31, SI-4	AUTH, CNFS, STCF, TXCF, TXIG	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(a)(3), 164.308(a)(4), 164.310(b), 164.310(c), 164.312(a), 164.312€	A.6.1.2, A.7.1.1, A.7.1.2, A.7.3.1, A.8.2.2, A.8.2.3, A.9.1.1, A.9.1.2, A.9.2.3, A.9.4.1, A.9.4.4, A.9.4.5, A.13.1.3, A.13.2.1, A.13.2.3, A.13.2.4, A.14.1.2, A.14.1.3

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
		PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity	SI-7	IGAU	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.312(b), 164.312(c)(1), 164.312(c)(2), 164.312(e)(2)(i)	A.12.2.1, A.12.5.1, A.14.1.2, A.14.1.3
		PR.DS-7: The development and testing environment(s) are separate from the production environment	CM-2	CNFS	C.F.R. § 164.308(a)(4)4	A.12.1.4
	Information Protection Processes and Procedures (PR.IP)	PR.IP-4: Backups of information are conducted, maintained, and tested periodically	CP-4, CP-6, CP-9	DTBK	C.F.R. §§ 164.308(a)(7)(ii)(A), 164.308(a)(7)(ii)(B), 164.308(a)(7)(ii)(D), 164.310(a)(2)(i), 164.310(d)(2)(iv)	A.12.3.1, A.17.1.2A.17.1.3, A.18.1.3
		PR.IP-6: Data is destroyed according to policy	MP-6	DIDT	C.F.R. §§ 164.310(d)(2)(i), 164.310(d)(2)(ii)	A.8.2.3, A.8.3.1, A.8.3.2, A.11.2.7
		PR.IP-9: Response plans (Incident Response and Business Continuity) and recovery plans (Incident Recovery and Disaster Recovery) are in place and managed	CP-2, IR-8	DTBK	C.F.R. §§ 164.308(a)(6), 164.308(a)(7), 164.310(a)(2)(i), 164.312(a)(2)(ii)	A.16.1.1, A.17.1.1, A.17.1.2
		PR.IP-10: Response and recovery plans are tested	CP-4, IR-3, PM-14	DTBK	C.F.R. § 164.308(a)(7)(ii)(D)	A.17.1.3
		PR.IP-12: A vulnerability management plan is developed and implemented	RA-3, RA-5, SI-2	MLDP	C.F.R. §§ 164.308(a)(1)(i), 164.308(a)(1)(ii)(A), 164.308(a)(1)(ii)(B)	A.12.6.1, A.18.2.2

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
	Maintenance (PR.MA)	PR.MA-1: Maintenance and repair of organizational assets is performed and logged in a timely manner, with approved and controlled tools	MA-2, MA-3, MA-5	CSUP, RDMP	C.F.R. §§ 164.308(a)(3)(ii)(A), 164.310(a)(2)(iv)	A.11.1.2, A.11.2.4, A.11.2.5
		PR.MA-2: Remote maintenance of organizational assets is approved, logged, and performed in a manner that prevents unauthorized access	MA-4	CSUP	C.F.R. §§ 164.308(a)(3)(ii)(A), 164.310(d)(1), 164.310(d)(2)(ii), 164.310(d)(2)(iii), 164.312(a), 164.312(a)(2)(ii), 164.312(a)(2)(iv), 164.312(b), 164.312(d), 164.312(e), 164.308(a)(1)(ii)(D)	A.11.2.4, A.15.1.1, A.15.2.1
	Protective Technology (PR.PT)	PR.PT-1: Audit/log records are determined, documented, implemented, and reviewed in accordance with policy	AC-4, AC-17, AC-18, CP-8, SC-7	AUDT	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(a)(5)(ii)(C), 164.310(a)(2)(iv), 164.310(d)(2)(iii), 164.312(b)	A.12.4.1, A.12.4.2, A.12.4.3, A.12.4.4, A.12.7.1
		PR.PT-3: The principle of least functionality is incorporated by configuring systems to provide only essential capabilities	AC-3, CM-7	AUTH, CNFS	C.F.R. §§ 164.308(a)(3), 164.308(a)(4), 164.310(a)(2)(iii), 164.310(b), 164.310(c), 164.312(a)(1), 164.312(a)(2)(i), 164.312(a)(2)(ii), 164.312(a)(2)(iv)	A.9.1.2
		PR.PT-4: Communications and control networks are protected	AC-4, AC-17, AC-18, CP-8, SC-7	DTBK	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.312(a)(1), 164.312(b), 164.312€	A.13.1.1, A.13.2.1

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
DETECT (DE)	Anomalies and Events (DE.AE)	DE.AE-1: A baseline of network operations and expected data flows for users and systems is established and managed	AC-4, CA-3, CM-2, SI-4	AUTH, CNFS	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.312(b)	none
		DE.AE-2: Detected events are analyzed to understand attack targets and methods	CP-2, IR-4, RA-3, SI -4	DTBK	C.F.R. § 164.308(6)(i)	A.16.1.1, A.16.1.4
	Security Continuous Monitoring (DE.CM)	DE.CM-1: The network is monitored to detect potential cybersecurity events	AC-2, AU-12, CA-7, CM-3, SC-5, SC-7, SI-4	AUTH, CNFS, EMRG, MLDP	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(a)(5)(ii)(B), 164.308(a)(5)(ii)(C), 164.308(a)(8), 164.312(b), 164.312(e)(2)(i)	none
		DE.CM-2: The physical environment is monitored to detect potential cybersecurity events	CA-7, PE-3, PE-6, PE-20	MLDP	C.F.R. §§ 164.310(a)(2)(ii), 164.310(a)(2)(iii)	none
		DE.CM-4: Malicious code is detected	SI-3	IGAU, MLDP, TXIG	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(a)(5)(ii)(B)	A.12.2.1
		DE.CM-6: External service provider activity is monitored to detect potential cybersecurity events	CA-7, PS-7, SA-4, SA-9, SI-4	RDMP	C.F.R. § 164.308(a)(1)(ii)(D)	A.14.2.7, A.15.2.1

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	**Category**	**Subcategory**	**SP800-53R4**	**IEC TR 80001-2-2**	**HIPAA Security Rule 45**	**ISO/IEC 27001**
		DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed	AU-12, CA-7, CM-3, CM-8, PE-3, PE-6, PE-20, SI-4	AUDT, CNFS, PAUT, PLOK, MLDP, NAUT, SGUD	C.F.R. §§ 164.308(a)(1)(ii)(D), 164.308(a)(5)(ii)(B), 164.308(a)(5)(ii)(C), 164.310(a)(1), 164.310(a)(2)(ii), 164.310(a)(2)(iii), 164.310(b), 164.310(c), 164.310(d)(1), 164.310(d)(2)(iii), 164.312(b), 164.314(b)(2)(i)	none
		DE.CM-8: Vulnerability scans are performed	RA-5	MLDP	C.F.R. §§ 164.308(a)(1)(i), 164.308(a)(8)	A.12.6.1
RESPOND (RS)	Response Planning (RS.RP)	RS.RP-1: Response plan is executed during or after an event	CP-2, CP-10, IR-4, IR-8	DTBK, SGUD, MLDP	C.F.R. §§ 164.308(a)(6)(ii), 164.308(a)(7)(i), 164.308(a)(7)(ii)(A), 164.308(a)(7)(ii)(B), 164.308(a)(7)(ii)(C), 164.310(a)(2)(i), 164.312(a)(2)(ii)	A.16.1.5
	Improvements (RS.IM)	RS.IM-1: Response plans incorporate lessons learned	CP-2, IR-4, IR-8	DTBK	C.F.R. §§ 164.308(a)(7)(ii)(D), 164.308(a)(8), 164.316(b)(2)(iii))	A.16.1.6

Cybersecurity Framework (CSF) v1.1				Sector-Specific Standards & Best Practices		
Function	Category	Subcategory	SP800-53R4	IEC TR 80001-2-2	HIPAA Security Rule 45	ISO/IEC 27001
		RS.IM-2: Response strategies are updated	CP-2, IR-4, IR-8	DTBK	C.F.R. §§ 164.308(a)(7)(ii)(D), 164.308(a)(8)	none
RECOVER (RC)	Recovery Planning (RC.RP)	RC.RP-1: Recovery plan is executed during or after an event	CP-10, IR-4, IR-8	DTBK	C.F.R. §§ 164.308(a)(7), 164.310(a)(2)(i)	A.16.1.5

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APPENDIX A – REFERENCES

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[2] R. M. M. O. J. Ross, Special Publication 800-160, Systems Security Engineering Considerations for a Multidisciplinary Approach in the Engineering of Trustworthy Secure Systems, Gaithersburg, MD: National Institute of Standards and Technology, 2016.

[3] Integrating the Healthcare Enterprise (IHE), [Online]. Available: http://wiki.ihe.net/index.php/Profiles#IHE_Radiology_Profiles.