White Paper

Challenging Security Requirements for US Government Cloud Computing Adoption

NIST Cloud Computing Public Security Working Group
NIST Cloud Computing Program
Information Technology Laboratory

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NOTE: All views expressed in this document by our contributors are their personal opinions and not that of the organization they represent.

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Executive Summary

On December 9, 2010, the Federal CIO introduced the 25 Point Implementation Plan to Reform Federal Information Technology Management. The plan's overall objective is to achieve greater efficiency in federal information technology while reducing costs through the use of shared resources and greater collaboration and consolidation. A major highlight of the 25 Point Implementation Plan is the shift to a "Cloud First" policy whereby each agency will identify three "must move" services within three months. Of the three, at least one of the services must be fully migrated to a cloud solution within 12 months and the remaining two within 18 months,[2] and to "evaluate safe, secure cloud computing options before making any new investments."[3]

The Federal Cloud Strategy, February 8, 2010, outlines a federal cloud computing program that identifies program objectives aimed at accelerating the adoption of cloud computing across the federal government. NIST, along with other agencies, was tasked with a key role and specific activities in support of that effort, including the delivery of the NIST Cloud Computing Technology Roadmap and the publication of other Special Publications that address the reference architecture, definitions, and security aspects of cloud computing. Accordingly, NIST has developed a series of Special Publications aimed at accelerating cloud computing adoption by federal agencies:

- NIST SP 500-291, *Cloud Computing Standards Roadmap*[4]
- NIST SP 500-292, *Cloud Computing Reference Architecture*[5]
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume 1, High-Priority requirements to Further USG Agency Cloud Computing Adoption*[6] (Draft)
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume II, Useful Information for Cloud Adopters*[7] (Draft)
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume III, Technical Considerations for USG Cloud Computing Deployment Decisions* (Draft)
- NIST SP 800-144, *Guidelines on Security and Privacy in Public Cloud Computing*[8]

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[2] http://www.cio.gov/documents/25-Point-Implementation-Plan-to-Reform-Federal IT.pdf
[3] http://www.cio.gov/documents/federal-cloud-computing-strategy.pdf
[4] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/StandardsRoadmap/NIST_SP_500-291_Jul5A.pdf
[5] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf
[6] http://www.nist.gov/itl/cloud/upload/SP_500_293_volumeI-2.pdf
[7] http://www.nist.gov/itl/cloud/upload/SP_500_293_volumeII.pdf

- NIST SP 800-145, *The NIST Definition of Cloud Computing*[9]
- NIST SP 800-146, *Cloud Computing Synopsis and Recommendations*[10] (Draft)
- Cloud computing security guidance to include NIST SP 800-137: *Information Security Continuous Monitoring for Federal Information Systems and Organizations*

In order to achieve adoption of cloud computing for the federal government, it is necessary to address the security and privacy concerns that federal agencies have when migrating their services to a cloud environment. To further exacerbate the situation, there are few documented details that directly address how to achieve some security aspects in a cloud environment.

The purpose of this document is to provide an overview of the high-priority security and privacy challenges perceived by federal agencies as impediments to the adoption of cloud computing. The document provides descriptions of the existing mitigations to these security and privacy impediments. If no mitigations are listed, then ongoing efforts that could lead to mitigations are described. In the cases where no ongoing efforts were identified, the document makes recommendations for possible mitigation or references existing best practices.

[8] http://csrc.nist.gov/publications/drafts/800-144/Draft-SP-800-144_cloud-computing.pdf
[9] http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf
[10] http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

Introduction

The NIST Cloud Computing Security Working group was created to achieve broad collaboration between federal and private stakeholders in efforts to review the security-related issues expressed by federal managers. Through its research, the working group identified a list of challenging security requirements that are perceived by federal managers as impediments to the adoption of cloud computing. This document focuses on the description of these challenging security requirements and identifies mitigations for each challenging issue when they exist. Where no mitigations are identified, the document provides either a description of activities that will serve to mitigate the risk created by the identified issue to an acceptable level, or makes recommendations for mitigations. The NIST Cloud Computing Working Group's charter and meeting minutes can be found at:
http://collaborate.nist.gov/twiki-cloud-computing/bin/view/CloudComputing/CloudSecurity.

This document is not intended to be a comprehensive or exhaustive list of the highest risks to federal data in a cloud environment. It is instead a practical look at the concerns expressed by federal managers and documented by a number of sources within government and private industry. The identified priorities in this document are grouped into two categories:

- *Process-Oriented Security Requirements*, and
- *Technically Oriented Security Requirements*.

Some of the challenging security requirements listed may have technical mitigations, but may require guidance or standards to ensure effective application. Others may have policies or mandates requiring implementation but lack the technical application in the cloud computing environment. The challenging security requirements discussed in this document are not listed by priority or importance. The priority and/or risks can vary widely based on the nature of the service moved to the cloud, the data associated with the service, and the cloud computing ecosystem (service model, deployment model, accountability, outsourcing, etc.).

Security Requirement Descriptive Template

The challenging security requirements listed in this document are structured as indicated in the following template:

Security Requirement Name (*a short, descriptive name used as title for the section*)

Description: *A short paragraph describing the challenges related to the requirement.*

Technical Considerations: *A brief description of the technical aspects of the challenging requirement and the rationale for considering it a challenging, high priority.*

Practical Example: *A brief example of where this security requirement is encountered.*

Importance: *A sentence indicating the importance of implementing this security requirement.*

Solution Maturity: *A sentence indicating the maturity level of the security requirement.*

Mitigation 1: <mitigation-name>

A description of the mitigation of the challenges encountered when implementing the security requirement, and an estimation of its efficiency.

Sufficiency Comment: *A brief, informal description of the effectiveness of this mitigation, and whether it depends on other mitigations.*

Mitigation 2: ...

…

Mitigation n: ...

References: *A collective list of the references pertaining to all mitigations for this security requirement.*

We anticipate that different mitigations will share references, so this field will ultimately exist at the end of the document in its own section but may initially exist per each requirement.

Process-Oriented Security Requirements

The process-oriented security requirements rely on human-centered processes, procedures, and guidance for mitigation.

1.1 NIST SP 800-53 Security Controls for Cloud-Based Information Systems

Description: This security requirement identifies the lack of clarity on the implementation of the security controls and assurance requirements described in NIST Special Publication (SP) 800-53 which must be applied to federal information and information systems in a cloud computing ecosystem.

Technical Considerations: The catalog of NIST SP 800-53 security controls defines minimum recommended management, operational, and technical controls for information systems based on impact categories. These controls should be applied to cloud-based information and information systems as well. The correct implementation of the security controls should be tested during an Assessment and Authorization (A&A) process for cloud ecosystems in a similar way any other federal information system is assessed and authorized for compliance in accordance with the Federal Information Security Management Act (FISMA) of 2002, H.R. 2458, Title III – *Information Security*[11] and of the Office of Management and Budget (OMB) Circular A-130, Section 8b (3), *Securing Agency Information Systems.*[12] While the US Government agencies retain the responsibility of compliance to the mandates of the Federal Information Security Management Act, depending upon which services or applications are migrated to the cloud, agencies must ensure that the Service Level Agreements (SLAs) legally binds the Cloud Provider, Broker or Carrier to implement all SP 800-53 security controls deemed appropriate and applicable.

The extensive use of virtualization technology in the cloud environment adds to the complexity of the implementation of some security controls. NIST SP 800-125, *Guide to Security for Full Virtualization Technologies*,[13] highlights security considerations of particular interest for virtualization solutions. These considerations are not intended to be comprehensive, nor is there any implication that unlisted security elements are unimportant or unnecessary. In addition to following the security recommendations presented in this publication, organizations implementing full virtualization solutions should also comply with Federal Information Processing Standard (FIPS) 200, *Minimum Security Requirements for Federal Information and Information Systems.*[14] This standard directs agencies to meet the identified minimum security requirements for federal information and information systems by selecting the appropriate

[11] http://csrc.nist.gov/drivers/documents/FISMA-final.pdf.
[12] http://csrc.nist.gov/drivers/documents/a130trans4.pdf
[13] http://csrc.nist.gov/publications/nistpubs/800-125/SP800-125-final.pdf
[14] http://csrc.nist.gov/publications/fips/fips200/FIPS-200-final-march.pdf

security controls and assurance requirements described in NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations,*[15] Revision 3.

Practical Example: NIST SP 800-53 controls are applicable to all information and information systems including those deployed in a cloud environment. The Federal Risk and Authorization Management Program (FedRAMP) provides a standard framework for Assessing and Authorizing (A&A) cloud computing services and products for multiagency use. The FedRAMP program employs a subset of existing SP 800-53 controls that are more applicable to cloud environments. In some cloud migration implementations, a federal agency might use a hybrid approach by migrating specific particular components of the system to cloud environments while the rest of the components continue to be hosted and managed within the agency. NIST SP 800-37, *Guide for Applying the Risk Management Framework to Federal Information Systems: A Security Life Cycle Approach,*[16] Revision 1, should be used as guidance to secure such systems since the use of cloud technology has little impact on the Risk Management Framework (RMF) process which is applied to these systems beyond documenting interfaces and referencing the applicable cloud A&A artifacts.

Importance: In accordance with FISMA, federal agencies have a responsibility to protect information and information systems commensurate with the risk and magnitude of the harm resulting from unauthorized access, use, disclosure, disruption, modification, or destruction, regardless of whether the information is collected or maintained by or on behalf of the agency; or whether the information systems are used or operated by an agency or by a contractor of an agency or other organization on behalf of an agency. Migration of federal systems or services to the cloud environment does not affect the authorizing official's responsibility and authority.

Solution Maturity: Mature. NIST SP 800-53 controls have been in use for a number of years and have been widely accepted by much of industry and required for use when securing federal systems.

Mitigation: NIST Risk Management Framework

FISMA and OMB policy requires cloud service providers (CSPs) that handle federal information or operating information systems on behalf of the federal government to meet the same security and privacy requirements as federal agencies. Security and privacy requirements for cloud service providers, including the security and privacy controls for information systems processing, storing, or transmitting federal information, are expressed in appropriate contracts or other formal agreements using the Risk Management Framework and associated NIST security standards and guidelines. Organizations can require cloud service providers to implement all steps in the Risk Management Framework described in NIST SP 800-37 with the

[15] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf
[16] http://csrc.nist.gov/publications/nistpubs/800-37-rev1/sp800-37-rev1-final.pdf

exception of the security authorization step, which remains an inherent federal responsibility that is directly linked to the management of risk related to the use of cloud services.

Organizations determine the security category of the information that will be processed, stored, or transmitted within the cloud-based information system in accordance with Federal Information Processing Standard (FIPS) 199, *Standards for Security Categorization of Federal Information and Information Systems.*[17] The standard provides a common framework and method for categorizing information and information systems to ensure that adequate levels of information security are provided, which are commensurate with the level of risk. The resulting security categorization drives the selection of required security and privacy controls. Since many security and privacy controls will require shared responsibilities between the cloud provider and cloud consumer depending on the chosen cloud service model (e.g., IaaS, PaaS, SaaS), organizations should provide the specific allocation of those responsibilities in their contracts and Service-Level Agreements (SLAs) with the cloud service providers.

Organizations should also ensure that the assessment of required security and privacy controls is carried out by qualified, independent third-party assessment organizations, to ensure that cloud service providers deliver appropriate evidence of control effectiveness. This evidence should be used by federal agencies for their initial authorization decisions. Federal agencies should also develop a continuous monitoring strategy and ensure that the strategy is implemented by the cloud service provider including defining how the security and privacy controls will be monitored over time (e.g., frequency of monitoring activities, rigor and extent of monitoring activities, and the data feeds provided to the organization from the cloud service provider). The continuous monitoring data feeds should be used by the agency for ongoing authorization decisions as part of its enterprise-wide risk management program.

The assurance or confidence that the risk from using cloud services is at an acceptable level depends on the trust that the organization places in the external cloud services provider. In some cases, the level of trust is based on the amount of direct control the organization is able to exert on the cloud service provider with regard to employment of the necessary security and privacy controls for protecting the federal information and the cloud service as well as and providing the evidence to support the effectiveness of those controls. The level of control is usually established by the terms and conditions of the contract or Service-Level Agreement with the cloud service provider (e.g., negotiating a contract or agreement that specifies detailed security and privacy controls for the provider).

The Federal Risk Authorization and Management Program (FedRAMP) provides a standard framework for assessing and authorizing cloud computing services and products for multiagency use and will satisfy many of the requirements above including defining minimum security and privacy requirements for cloud-based information systems. The security and privacy controls from NIST SP 800-53 are defined for low- and moderate-impact information

[17] http://csrc.nist.gov/publications/fips/fips199/FIPS-PUB-199-final.pdf

being processed, stored, and transmitted within cloud-based information systems delivering cloud services. Continuous monitoring controls are also defined. A conformity assessment program will provide opportunities to obtain independent third-party assessment services to determine security and privacy control effectiveness. FedRAMP is derived from and based upon the NIST Risk Management Framework as described in NIST SP 800-37.

Sufficiency Comment: The NIST 800-53 guidelines have been broadly developed from a technical perspective to complement similar guidelines for national security systems and may be used for such systems with the approval of appropriate federal officials exercising policy authority over such systems. State, local, and tribal governments, as well as private sector organizations are encouraged to consider using these guidelines, as appropriate.

References:

- Federal Information Security Management Act (FISMA) of 2002, H.R. 2458, Title III—*Information Security*.
- Office of Management and Budget (OMB) Circular A-130, Section 8b(3), *Securing Agency Information Systems*.
- NIST SP 800-125, *Guide to Security for Full Virtualization Technologies.*
- FIPS 200 *Minimum Security Requirements for Federal Information and Information Systems*.
- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3.
- NIST SP 800-37, *Guide for Applying the Risk Management Framework to federal information Systems: A Security Life Cycle Approach*, Revision 1.
- FedRAMP: http://www.fedramp.gov.

1.2 Cloud Audit Assurance and Log Sensitivity Management

Description: This security requirement identifies the needs of federal agencies to gain assurance that:

- Important events are monitored;
- Sensitive/private audit logs are appropriately protected;
- Integrity of audit data used for initial or continuous auditing purposes ((e.g., audit logs, data collected by Security Content Automation Protocol [SCAP]) is protected; and
- Audit data interchange incompatibility is resolved.

Technical Considerations: The NIST Cloud Computing Reference Architecture introduces a Cloud Auditor into an organization's computing model. A cloud auditor is a party that can perform an independent examination of cloud service controls with the intent to express an opinion thereon. Audits are performed to verify conformance to standards through review of objective evidence. This fact raises important questions about monitoring and auditing requirements:

- Who is doing any particular monitoring or auditing task?
- Who is informed of the results of any particular monitoring or auditing task, and when?
- What is an appropriate level of abstraction and summarization in the aforementioned results?

In this context, it is important to note the distinction between monitoring and reporting tasks. This requirement addresses the monitoring task and how the results from this activity such as raw log data or aggregated reports are handled. Later in this document, in Section 4.9, we discuss the security requirements and guidance aimed at standardizing the reporting task. Monitoring a system for anomalies is in the cloud system operator's purview. Monitoring produces results that should be compiled in a comprehensive report and then delivered to other stakeholders of the system.

Cloud providers may be required to store and/or forward log data to designated collection points or to aggregation storage media. Regardless of the elected method for the handling of the system's log data, in order to assure that the monitored data is secure, steps must be taken to protect it in transit and at rest. There are many methods for deployment of encryption that ensures data protection while guaranteeing it can be accessed when requested. Data may be forwarded to external entities for automated inspection. An IPSec-like encryption method may provide the best performance but may not be suitable for highly mobile data scenarios.

Practical Example: Operational requirements for the monitoring and/or auditing of cloud environments can vary significantly depending on many factors. For example, a private cloud restricted to limited physical locations may not be as inherently mobile as a public cloud where data may be relocated much more dynamically. In such a private cloud scenario, monitoring sensors could be deployed without the concerns of their iterative relocating or modification. In a public or hybrid cloud, multi-tenancy concerns could emerge depending on the data monitored and/or captured. If data is moved dynamically, providers and subscribers could face challenges in ensuring that subscribers are able to monitor and receive reports specific to their data.

In a public cloud scenario, the provider has operational control of the environment and may offer a baseline of monitoring services. SLAs or contracts should be used to ensure that specific requirements for monitoring and metrics are satisfied. In any SLA or contract with the CSP, the customer should specify measurable monitoring and reporting standards. The contract should spell out the measures to be taken if any SLA requirements are not met. A periodic review of the SLAs and their parameters should be spelled out in the contract. Although the CSP will be monitoring tasks, the customer is not absolved from their responsibility to monitor and audit aspects of the information system that it may operate or manage.

Importance: Cloud operational auditing and continuous monitoring (CM) is a requirement for all federal systems. The objective of the operational CM program is to determine the effectiveness of the deployed security controls and the potential need to change or supplement

the control set, taking into account any proposed/actual changes to the information system or its environment of operation.

It is important to note that this section discusses the auditing and continuous monitoring requirements from the operational perspective and not the FedRAMP's ongoing Assessment and Authorization, also referred to as Continuous Monitoring in the FedRAMP's *Concept of Operations (CONOPS),*[18] document. However, FedRAMP does work in coordination with the Department of Homeland Security (DHS) to establish a framework for continuous monitoring, incident response and remediation, and FISMA reporting. The FedRAMP's Assessment and Authorization process is further discussed in the next section.

Solution Maturity: Immature. While effective monitoring solutions have been in use for quite some time, the high mobility inherent to the cloud computing environment and multi-tenancy provide unique challenges on how specific data can be monitored.

Mitigation 1: Risk Management Framework

The NIST Risk Management Framework (RMF) (NIST SP 800-37, *Guide for Applying the Risk Management Framework to Federal Information Systems: A Security Life Cycle Approach,*[19] Revision 1) provides guidance to federal system owners to take a risk-based approach to securing systems. This approach is operationally focused and is intended to facilitate the monitoring, documenting, and mitigation of threats on a regular, if not near real-time, basis. Continuous monitoring is step 6 of NIST SP 800-37's six-step Risk Management Framework. While many vendors are seeking to offer automated vulnerability monitoring tools, it is important to realize there is more to an effective continuous monitoring program than a suite of automated tools.

NIST 800-37 describes an effective operational continuous monitoring program as one that includes:

- Configuration management and control processes for information systems;
- Security impact analyses on proposed or actual changes to information systems and environments of operation;
- Assessment of selected security controls (including system-specific, hybrid, and common controls) based on the defined continuous monitoring strategy;
- Security status reporting to appropriate officials; and
- Active involvement by authorizing officials in the ongoing management of information system-related security risks.

Sufficiency Comment: The RMF and NIST SP 800-53, Revision 3, provide adequate guidance and controls related to the securing of audit data.

[18] http://www.gsa.gov/portal/category/102371
[19] http://csrc.nist.gov/publications/nistpubs/800-37-rev1/sp800-37-rev1-final.pdf

Mitigation 2: Audit Data Interchange

The Cybersecurity Information Exchange Techniques (CYBEX) project was launched by the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T). CYBEX provides for the structured exchange at known assurance levels of information about the measurable "security state" of systems and devices, about vulnerabilities, about incidents such as cyber attacks, and about related knowledge "heuristics." The CYBEX initiative imports more than twenty "best of breed" standards for platforms developed over the past several years by government agencies and industry to enhance cybersecurity and infrastructure protection. Pulling these platforms together in a coherent way provides for:

- "locking down" on-line systems to minimize vulnerabilities;
- capturing incident information for subsequent analysis when harmful incidents occur; and
- discovering and exchanging related information with some degree of assurance.

The CYBEX Model includes:

- structuring cybersecurity information for exchange purposes;
- identifying and discovering cybersecurity information and entities;
- establishment of trust and policy agreement between exchanging entities;
- requesting and responding with cybersecurity; and
- assuring the integrity of the cybersecurity information exchange.

Real-time Inter-network Defense (RID) [RFC6045, RFC6046] provides a proactive inter-network communication method to facilitate sharing incident handling data while integrating existing detection, tracing, source identification, and mitigation mechanisms for a complete incident handling solution. The need for RID and related standards for cloud computing is called by the consumer's requirements to communicate incident information quickly and efficiently with their service providers. The escalation points from detection to investigation and mitigation may vary based on the SLA, but the incident information and its transfer should be secure and standardized to enable the use of various vendor platforms. The incident information may be exchanged for the purposes of situational awareness or for an ongoing investigation with a request to mitigate or stop the incident. Benign incidents (e.g., configuration issues or availability issues due to IT problems) require quick reporting and fast mitigation methods. These incidents may be communicated via the described protocols.

References:

- CSA Cloud Audit - http://cloudaudit.org/CloudAudit/Home.html
- CSA/ CSC - Cloud Trust Protocol - http://assets1.csc.com/lef/downloads/Digital_Trust_in_the_Cloud.pdf

- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3
- PCI DSS 10.5.5 – File Integrity Monitoring
- ISO27001 10.10.3 – Protection of Log Information
- NIST SP 800-92, *Guide to Computer Security Log Management*
- CSA CCM SA-14 – Audit Logging / Intrusion Detection
- CYBEX Overview –

  http://www.itu.int/dms_pub/itu-t/oth/0A/0D/T0A0D00001D0004PDFE.pdf

1.3 Cloud Certification and Accreditation

Description: This requirement addresses the need to certify and accredit cloud solutions with confidence.

Technical Considerations: The risk management process changes the traditional focus of Certification and Accreditation (C&A) from a static, procedural activity to an increasingly dynamic approach that provides the capability for more effective management of information system-related security risks in a highly diverse environment of complex and sophisticated cyber threats, ever-increasing system vulnerabilities, and rapidly changing missions.

The Certification and Accreditation (C&A) terminology used in this section has been lately updated to "Assessment and Authorization (A&A), as used by the Federal Risk and Authorization Management Program (FedRAMP), a government-wide program that provides a standardized approach to security Assessment, Authorization, and Continuous Monitoring[20] (also refer to as ongoing A&A) for cloud products and services.

To preserve traceability to the initial concern expressed by different agencies, we will use the terms interchangeably, with the understanding that they are referring to the same process.

Practical Example: The FedRAMP A&A process provides a methodology for assessing and authorizing cloud offerings to federal cloud consumers. Systems that are not migrated to a cloud environment are subject to undergo certification and accreditation based on the NIST SP 800-37, *Guide for Applying the Risk Management Framework to Federal Information Systems: A Security Life Cycle Approach*,[21] Revision 1. A hybrid approach must be considered for migration scenarios that include interfaces with cloud-based services and applications with boundaries established, and artifacts produced, by either process.

[20] http://www.gsa.gov/portal/category/102995
[21] http://csrc.nist.gov/publications/nistpubs/800-37-rev1/sp800-37-rev1-final.pdf

The diagram in Figure 1 summarizes the Risk Management and the Certification and Accreditation tasks indicating, with different color codes, the responsible parties.

Solution Maturity: On December 8, 2011, the Office of Management and Budget (OMB) issued the FedRAMP Policy memo, establishing FedRAMP and its role in the Assessment and Authorization process for cloud systems. In 2012, the FedRAMP Program Management Office (PMO) issued a security control baseline at the low- and moderate-impact levels and a Concept of Operations (CONOPs). The FedRAMP PMO expects to launch an Initial Operating Capability (IOC) in June 2012.

Mitigation 1: FedRAMP Assessment and Authorization

The FedRAMP program provides a cost-effective, risk-based approach for assessing and authorizing cloud offerings to cloud consumers, therefore facilitating the adoption and use of cloud services. A key element to successful implementation of cloud computing is a security program that addresses the specific characteristics of cloud computing and provides the level of security commensurate with specific needs to protect government information. Effective security management must be based on risk management and not only on compliance. By adhering to a standardized set of processes, procedures, and controls, agencies can identify and assess risks and develop strategies to mitigate them. Additional information on FedRAMP can be found at: http://www.fedramp.gov.

Sufficiency Comment: The FedRAMP process is based on the NIST Risk Management Framework and leverages the NIST SP 800-53[22] (Revision 3) security controls for information and information systems. NIST SP 800-53 (Revision 3) controls have been proven adequate to secure low and moderate systems.

References:

- FedRAMP, http://www.fedramp.gov
- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3, http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf

[22] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf

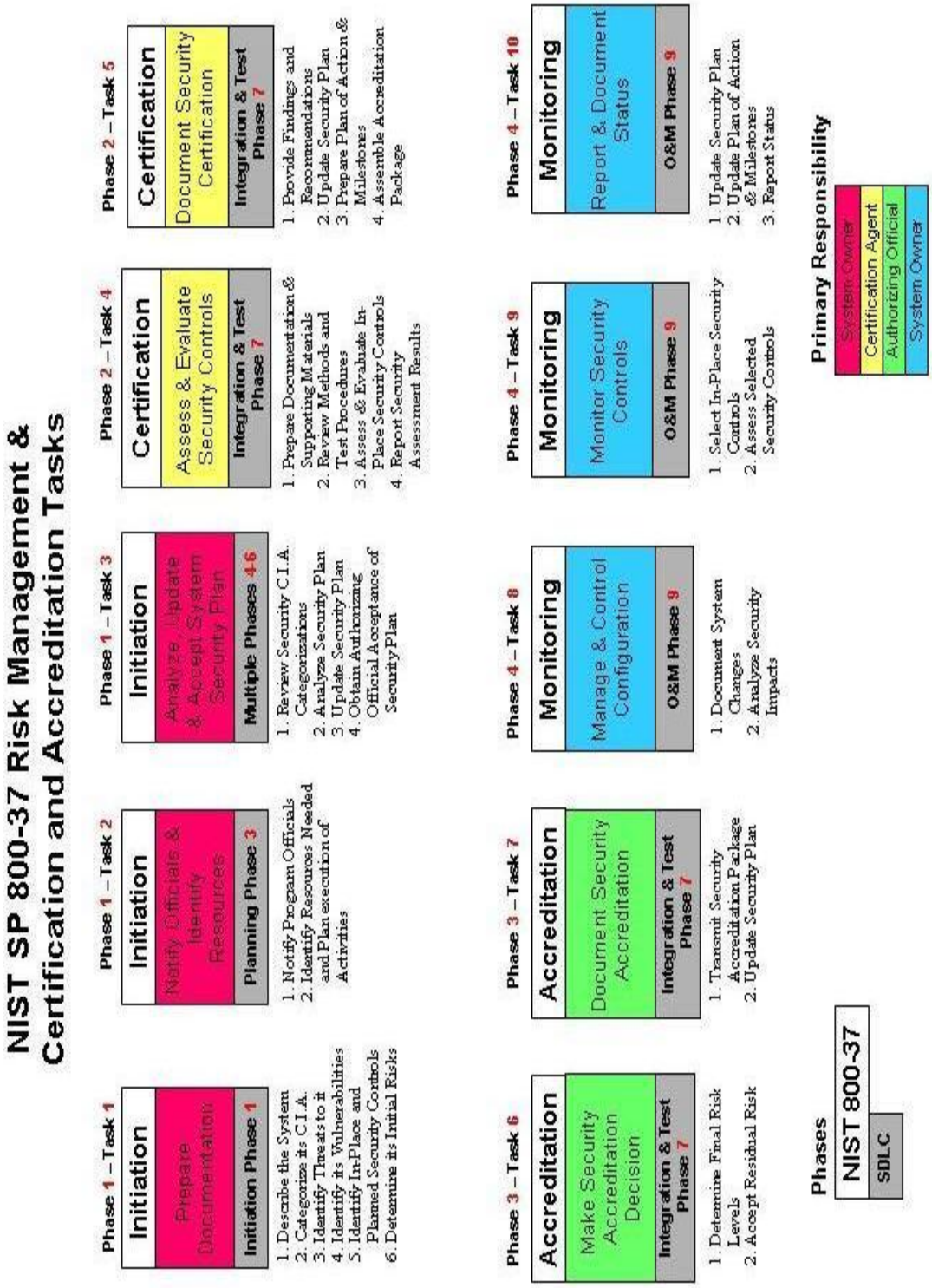

Figure 1: NIST SP 800-37 Risk Management & Certification and Accreditation

1.4 Needed Electronic Discovery Guidelines

Description: This requirement addresses the need for clear guidelines to the identification, collection, processing, analysis, and production of electronically stored information (ESI) in response to a lawful authority, while protecting customer's privacy and for a roadmap to ensure that service providers are preserving electronic records with sufficient evidential weight and chain of custody controls.

Technical Considerations: Current electronic discovery (e-discovery) tools cannot be effectively implemented in a cloud environment. Some present options to meet e-discovery requirements include migrating potentially large amounts of data to a non-cloud or searchable platform where tools can be effective. Depending upon the amount of data to be searched, such solutions are potentially costly, may be time–consuming, and are generally impractical.

Practical Example: Electronic discovery[23] refers to the process of identifying and producing relevant ESI, including metadata and electronic backup materials, in response to civil and criminal litigations. Once such litigation is reasonably anticipated (e.g., receipt of a letter threatening a lawsuit), a party has a legal obligation to suspend destruction of such ESI, by issuing a "litigation hold" to all individuals and entities maintaining ESI on the party's behalf. Failure to take proper and adequate steps to preserve such ESI can result in serious legal sanctions against a party. In a cloud computing ecosystem, there is a significantly increased risk of failing to obey the legal e-discovery obligations, since the service provider may be unable or unwilling to halt routine destruction of responsive ESI, due to technical, cost, legal or other reasons, or may be incapable of preventing data commingling. For example, a cloud provider's archival capabilities may not preserve the original metadata as expected, causing spoliation (i.e., the intentional, reckless, or negligent destruction, loss, material alteration, or obstruction of evidence that is relevant to litigation), which could negatively impact litigation. Likewise, the nature of cloud storage (e.g., widely dispersed servers or databases located domestically or even overseas) may complicate the ability to identify, preserve, and retrieve responsive ESI in a timely fashion, further jeopardizing the agency's ability to meet its legal e-discovery obligations.

Responsibilities of the Federal Consumers:

The cloud consumer is responsible for preserving evidence and for the issuance of litigation hold notices to cloud providers who have any pertinent ESI. If required evidence is lost or damaged, the customer may be fined and/or sanctioned by the court despite any fault or failure on the part of the cloud provider, thus it is incumbent upon the cloud customer to verify that robust processes are in place to ensure preservation and facilitate ESI collection. Additionally, failure to understand where pertinent ESI is located could result in exposure of data beyond the

[23] http://www.cio.gov/Documents/Privacy-Recommendations-Cloud-Computing-8-19-2010.docx

scope of the electronic discovery request, or data belonging to customers who are not parties to the specific discovery request – possibly violating their privacy.

Responsibilities of the Cloud Provider:

The cloud provider is responsible for identifying and producing relevant electronically stored information to lawful authority when presented with a lawful demand for such information. This may be a one-time request for stored information or it may be a request for dynamic access to data akin to a wiretap. These requests often include a specific deadline for cooperation or surrendering of the information, and the provider may face penalties if they are unable or unwilling to comply.

Importance: Meeting electronic discovery requests can pose a significant challenge when electronically stored information is in the cloud.

Solution Maturity: Involving legal/e-discovery subject-matter experts in cloud service negotiation and mapping of business processes to identify points where ESI is generated, processed, and/or stored on cloud-based systems are solutions which can be implemented immediately and offer reasonable mitigation of risk. Automation of ESI collection and preservation management is potentially a future mitigation, but limitations of current tools and the evolving nature of the cloud environments result in a less than optimal solution at present.

Mitigation 1: When procuring a cloud service, customers must gain an understanding of how the cloud provider processes electronic discovery and litigation holds. The customer should acquire knowledge of key issues – such as the length of time the provider takes to enforce a litigation hold (i.e., prevent the modification and/or destruction of pertinent evidence) or respond to an electronic discovery request and what steps are required to invoke these processes, types of logs and metadata retained including life cycles of same, dependencies on other providers, evidentiary chain of custody and storage, and additional processing fees that may be incurred. Having a subject-matter expert discuss these processes with the cloud provider is preferable to a checklist, due to the variances of cloud environments and the specialized knowledge requirements around electronic discovery and preservation of evidence. Specific wording or clauses may need to be inserted into the cloud contract to ensure that cloud providers share the burden for failure to properly secure and maintain evidence once a hold or request has been properly initiated.

Sufficiency Comment: While this solution provides a reasonable level of risk mitigation, it is dependent upon the existence and availability of in-house knowledge, or the willingness to procure such, and to invest the time and resources needed. There may also be unanticipated requests for specific metadata or unstructured data not routinely collected or stored by either the cloud customer or provider that limit their availability, and these must be handled on a case-by-case basis.

Mitigation 2: Mapping of the significant business process and ESI

Customers should undertake the effort to map significant business processes and ESI created, processed, and/or stored as a result that would have a high likelihood of being the target of an electronic discovery request. Where possible, the proactive collection, indexing, and storage of ESI that has a reasonable expectancy of falling within the scope of future litigation or discovery requests (such as email) may lessen the dependency on cloud providers – particularly if the ESI can be stored on systems under the direct control of the customer. A records-retention policy defining the forms of ESI routinely collected and archived, as well as ESI formats not retained, can assist in refining the scope of this effort.

Sufficiency Comment: While this solution provides a reasonable level of risk mitigation, it is dependent upon the ability and willingness of the customer to map key business processes and the discovery-pertinent ESI generated, processed, or stored as a result. There is a cost associated with mapping processes and storing ESI, and these should be balanced against costs of electronic discovery and litigation hold involving cloud providers, costs of hiring e-discovery specialists to handle ESI projects, and the possibility of fines and/or sanctions as the result of an inability to preserve or produce requested evidence.

Mitigation 3: Providers should undertake the effort to understand the requirements for lawful intercept, national security letters, subpoena, and e-discovery. Providers must make a timely response and provide information for a specific tenant without collateral information from other tenants. Providers must be able to locate and provide access to data or communication channels that are specific to a single tenant.

Sufficiency Comment: Existing hypervisor platform technologies do not incorporate the necessary features to support these tasks. Providers will need to incorporate in-house or third-party solutions.

References:

Federal Rules of Civil Procedure (2010)

1.5 Needed Cloud Privacy Guidelines

Description: This requirement addresses the need to build confidence in cloud solutions that provide privacy of data and personally identifiable information (PII) protection.

Technical Considerations: Regardless of the cloud offering selected, all federal managers have the responsibility to ensure privacy of data and the protection of PII. NIST SP 800-122, *Guide to Protecting the Confidentiality of Personally Identifiable Information (PII),*[24] was created to explain the importance of protecting the confidentiality of PII in the context of

[24] http://csrc.nist.gov/publications/nistpubs/800-122/sp800-122.pdf

information security and its relationship to privacy using the Fair Information Practices, which are the principles underlying most privacy laws and privacy best practices. PII should be protected from inappropriate access, use, and disclosure. The NIST SP 800-122 document provides practical, context-based guidance for identifying PII and for determining what level of protection is appropriate for each instance of PII. The document also suggests safeguards that may offer appropriate levels of protection for PII and provides recommendations for developing response plans for incidents involving PII. Organizations are encouraged to tailor the recommendations to meet their specific requirements.

Practical Example: Federal managers must work to ensure that SLA and/or contracts require cloud service providers to adhere to existing guidance regarding privacy and PII information. Ultimately, it is the system owner and approving authority that are responsible for the proper handling of such data.

Importance: The Privacy Act of 1974, 5 U.S.C. § 552a[25], As Amended, and the Computer Matching and Privacy Protection Act of 1988[26] require the protection of personal information held by agencies. Additionally, in the commercial arena, the FTC's Fair Information Practices have established a framework under which individuals can depend upon certain privacy-related rights and expectations when engaging in business transactions with both online and brick-and-mortar merchant entities.[27] The OMB Memorandum M03-22 established the guidance for federal agencies to implement the E-Government Act of 2002. This guidance provided for individual agencies to develop Privacy Impact Assessments (PIAs) to enable them to understand the privacy implications of the data that they were managing within their systems and to ensure that the proper controls were in place to protect the data according to established law.

End-users (Data Owners):

The American public and other individual stakeholders - whose data is currently managed by federal agencies yet will potentially be put into the hands of third parties in cloud-deployed systems - have a very strong and visceral concern about the protection of their personally identifiable information. They have benefited, thus far, from precedent-setting tenets and principles, such as those defined in The Privacy Act of 1974, 5 U.S.C. § 552a as amended and the Computer Matching and Privacy Protection Act of 1988 to ensure protection of personal information held by agencies. Additionally, in the commercial arena, the FTC's Fair Information Practices have established a framework under which individuals can depend upon certain privacy-related rights and expectations when engaging in business transactions with both online and brick-and-mortar merchant entities. These provisions have come to be established globally as basic expectations of privacy rights by individuals.

[25] http://www.justice.gov/opcl/privstat.htm
[26] http://www.irs.gov/irm/part11/irm_11-003-039.html
[27] http://www.ftc.gov/reports/privacy3/fairinfo.shtm

The nature of cloud computing, however, leverages the economies of scale, geographies, and resource balancing across an ecosystem of partners in the value chain that encompasses cloud service providers, brokers, and other relevant roles. This broad and potentially nontransparent cloud provision network runs the risk of undoing the trust and confidence that individuals have come to have in the federal agencies with respect to the handling of their personal data. Therefore, the greatest challenge for the agencies is to be able to maintain and sustain that confidence level, while being able to ensure a chain-of-trust across the architecture, policies, and legal structures that are established with their cloud providers.

Cloud Customers (Federal Agencies):

OMB Memorandum M03-22 established the guidance for federal agencies to implement the E-Government Act of 2002. This guidance provided for individual agencies to develop Privacy Impact Assessments (PIAs) to enable them to understand the privacy implications of the data that they were managing within their systems and to ensure that the proper controls were in place to protect the data according to established law. Individual agencies expounded upon these PIAs to issue additional guidance for the cross-agency privacy governance activities. (References to these individual PIAs and procedures for various agencies are provided below.)

The basic structure of the PIA is based upon knowing the data flows of personally identifiable information, the secure protection and ultimate deletion/retention of the data across the life-cycle – and the ability to ensure, through pre-assessments, audits, and monitoring activities, that any third parties involved in the processing or handling of the data did so in a manner that was consistent and complied with the appropriately defined agency controls.

Solution Maturity: Efforts to address privacy issues in a cloud environment through SLAs are evolving.

Mitigation 1: Ensure that cloud providers protect the personal information to the requisite levels of protections:

a) That have already been established for federal agencies' existing systems; and

b) That are being finalized to define cloud-specific controls for federal agencies in the near term.

Addition information is found in NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*,[28] Revision 3; NIST 800-53 Appendix J, *Security and Privacy Controls for Federal Information Systems and Organizations*,[29] and NIST SP 800-146, *Cloud Computing Synopsis and Recommendations*[30] (Draft). Additionally,

[28] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf
[29] http://csrc.nist.gov/publications/drafts/800-53-Appdendix-J/IPDraft_800-53-privacy-appendix-J.pdf
[30] http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

Service-Level Agreements and other legal instruments need to be established between the cloud customer and the cloud provider, although ultimately the cloud customer is still responsible for the protection of the data.

Sufficiency Comment: Cloud customers (federal agencies) must limit their choice of cloud providers to those that will allow them the required degree of assurance and assurance testing to ensure sustained protection of personal information in the cloud. Alignment of cloud providers to those controls and providing "proof" of implementation are still in question.

Mitigation 2: Maintain confidence of the individuals whose personal data the federal agencies are managing.

Cloud customers (federal agencies) should consistently assess the scope of the personally identifiable information that they manage within their systems through the PIA processes in order to determine the degree of risk associated with the type of data that is being maintained. For instance, health information (under strict requirements of HIPAA and HITECH requirements) should be classified in such a manner that proper evaluations as to appropriate migration to a public, hybrid public/private or private cloud can be performed by each agency. Education and outreach efforts should be done to assure individuals that the privacy controls that currently exist to protect their personal information will be retained despite migration to a cloud environment. (This mitigation is contingent upon the ability to reach Mitigation 1.)

Sufficiency Comment: PIA questions and processes have been well-established. Cloud-specific implementations of the cloud-deployed data flow will impact the ability to assess all sections of the requisite PIAs and without the involvement and assurance of the cloud provider. The PIAs should enable the Cloud Customers to assess which data can be migrated to the cloud in a low-risk manner.

Mitigation 3: Ensure that cross-jurisdictional privacy issues are addressed and incorporated in any agency's cloud deployment if it will collect, manage, retain, or otherwise process data that comes under the scope of global data protection regulations. These global requirements may fall outside the technology scope of the NIST Reference Architecture and may not even be consistently automated across IT processes (for instance, manual collection of data that ultimately ends up in a database hosted in the cloud). Although alignment activities are taking place between the United States and the European Union (EU) to address disparities in privacy-relevant legislation, areas of non-agreement remain. This mitigation requires a proactive strategy that addresses the physical location of the data in the cloud, awareness of and agreements regarding the cross-border transfer of any relevant data, and the ability to ensure the end user (data owner) involvement in the modification or requested deletion of their data (where appropriate). These are established legal rights of citizens outside of the United States; yet awareness to these intricacies is not well-known across many of the agencies and system owners today. Therefore, formulation of a strategy to address these unique situations (for which there have been real-world situations in which data access was withheld/disrupted for federal

agencies due to these legal differences) will be required. Nonpolitical mitigations (or at least stop-gap measures in the interim) would include geo-tagging of data to ensure that relevant data does not cross international borders, stricter or modified metadata and data classifications, etc.).

Sufficiency Comment: Beyond Safe Harbor and Model Contracts established between the EU and the United States, no other tenets exist to address the transfer of data between the two geographic jurisdictions. Cloud deployments may have to be continent-specific initially until these policies/procedures are established. The scope of federal agencies that will be impacted by international data and geopolitical considerations will need to be understood.

References:

- General Privacy Laws Governing Federal Agencies
- Privacy Act of 1974 http://www.justice.gov/opcl/privstat.htm
- E-Government Act of 2002 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=107_cong_public_laws&docid=f:publ347.107.pdf
- OMB Privacy Guidance and Policies
- Privacy Act Implementation, Guidelines and Responsibilities http://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/implementation_guidelines.pdf
- OMB Circular No. A-130, *Management of Federal Information Resources* http://www.whitehouse.gov/omb/circulars_a130_a130trans4
- OMB Memorandum M-99-18, *Privacy Policies on Federal Web Sites* http://www.whitehouse.gov/omb/memoranda_m99-18
- OMB Memorandum M-03-22, *OMB Guidance for Implementing the Privacy Provisions of the E-Government Act of 2002* http://www.whitehouse.gov/omb/memoranda_m03-22
- OMB Memorandum M-06-15, *Safeguarding Personally Identifiable Information* http://www.whitehouse.gov/sites/default/files/omb/assets/omb/memoranda/fy2006/m-06-15.pdf
- OMB Memorandum M-07-16, *Safeguarding Against and Responding to the Breach of Personally Identifiable Information*, http://www.whitehouse.gov/sites/default/files/omb/assets/omb/memoranda/fy2007/m07-16.pdf
- OMB Memorandum M-10-22, *Guidance for Online Use of Web Measurement and Customization Technologies*, http://www.whitehouse.gov/sites/default/files/omb/assets/memoranda_2010/m10-22.pdf

- OMB Memorandum M-10-23, *Guidance for Agency Use of Third-Party Websites and Applications*, http://www.whitehouse.gov/sites/default/files/omb/assets/memoranda_2010/m10-23.pdf
- Other OMB Guidelines, Additional Guidance from OMB regarding Privacy Regulations http://www.whitehouse.gov/omb/inforeg_infopoltech#prm
- DOJ Privacy Act Regulations, *Protection of Privacy and Access to Individual Records Under the Privacy Act of 1974*, 28 C.F.R. pt. 16 subpart D, http://www.justice.gov/opcl/regulations.htm
- DOJ Privacy Act Regulations, *Exemption of Records Systems Under the Privacy Act*, 28 C.F.R. pt. 16 subpart E. http://www.access.gpo.gov/nara/cfr/waisidx_10/28cfr16_10.html
- Incident Response Procedures for Data Breaches Involving Personally Identifiable Information http://www.justice.gov/opcl/breach-procedures.pdf
- DOJ Overview of Privacy Act http://www.justice.gov/opcl/1974privacyact-overview.htm
- Department of Homeland Security,

  http://www.dhs.gov/xlibrary/assets/privacy/privacy_pia_guidance_may2007.pdf
- U.S. Security and Exchange Commission,

  http://www.sec.gov/about/privacy/piaguide.pdf
- FDIC, http://fcx.fdic.gov/about/privacy/assessments.html
- Department of Education, http://www2.ed.gov/notices/pia/index.html
- Department of Defense, http://www.dtic.mil/whs/directives/corres/pdf/540016p.pdf

1.6 Clarity on Cloud Actors Security Roles and Responsibilities

Description: This security requirement addresses the need for clarity regarding the roles and responsibilities among cloud actors (e.g., cloud consumer and cloud service provider) for the implementation of required NIST SP 800-53 security controls. The actor most able to observe and configure specific components of a cloud implementation is in the best place to implement a relevant control.

Technical Considerations: Careful planning of security activities should be considered in concert with the design of a migration or cloud deployment effort. It is critical to ensure that the appropriate ability to meet the operational responsibilities necessary to maintain a system's security posture is planned and executed whether a system component is deployed to a cloud or self-hosted.

Practical Example: When migrating applications and services to a cloud environment, a combination of deployment and service models may be used to satisfy requirements. Such variation requires careful examination of the roles and responsibilities required to secure and monitor cloud and/or internally hosted systems.

Importance: The data owner (typically cloud customer) is responsible for compliance with laws and regulations including the proper security controls around their data, regardless of its location or the involvement of other parties.

Cloud Consumer:

When customer data is off-premise and under the control of a third party, such as the cloud provider, cloud broker, or cloud carrier, the ability of the data owner to implement security controls is often limited. In cloud computing environments, the implementation of controls is going to be largely dependent upon the type of service (IaaS, PaaS, SaaS), type of cloud (private, public, community, hybrid), type of controls (i.e., physical versus logical), and the specifications of responsibility delineated in the cloud contract. Customers must choose services accordingly and understand the risks and limitations of third-party control – i.e., customers can outsource the functionality of a role/responsibility, but will still hold the legal liability for failure to secure data.

Cloud Provider/Broker/Carrier:

Cloud providers/brokers/carriers have increasing responsibilities for implementing and maintaining security depending on the cloud types and service types offered. For example, physical security controls in the cloud environment will have to be implemented by a party which has access to the physical property where the assets reside – a role likely performed by the cloud provider, broker, or carrier. Providers/brokers/carriers should provide statements of the security controls that they implement and maintain for each of the cloud architectures and services offered.

Solution Maturity: Cloud Security Alliance has published a Cloud Controls Matrix which provides a good reference point and denotes applicability to cloud service type (IaaS, PaaS, SaaS) and scope (provider, tenant). The effectiveness of the solution is dependent upon the cloud customer's capacity to understand the provider's posture on security controls for the services offered and their ability to mitigate specific risks and meet customer requirements. The solution is also dependent upon the customer's willingness to choose a cloud service or architecture that permits more direct control for addressing specific security requirements.

Mitigation 1: Provider-consumer guidelines

Guidelines defining and documenting the roles and responsibilities of cloud providers and consumers should clarify that even though the responsibility for protecting the information remains with the consumer, the terms of a contract between cloud consumer and a cloud provider can place an obligation on the provider to protect information. To satisfy due diligence and due care requirements for securing their data, cloud customers must ensure that

the contract with the cloud provider/broker/carrier specifies who the responsible party (or parties) for implementing and maintaining security controls are and provides rights of action for failure to implement or maintain same.

Sufficiency Comment: The solution provides a reasonable degree of risk mitigation but is dependent upon customer willingness to define security roles/responsibilities and negotiate them with the cloud provider(s).

Mitigation 2: Cloud type/service selection

In cases where a larger degree of direct control over security roles/responsibilities and the ability to implement security controls is needed, cloud customers may consider utilization of a type of service (i.e., PaaS, or IaaS instead of SaaS) and/or a cloud type (on-premise versus off-premise, private versus public cloud) which will allow that requirement to be fulfilled.

Sufficiency Comment: The solution can provide reasonable degree of risk mitigation but there may be increased cost in choosing services and/or architectures that allow more direct control, and these costs should be weighed against security requirements and acceptable risk levels.

References:

Cloud Security Alliance, *The Cloud Controls Matrix*.

1.7 Trustworthiness of Cloud Operators

Description: This requirement addresses the need to ensure that individuals with physical and logical access to subscriber data are properly vetted and screened periodically to ensure trustworthiness.

Technical Considerations: Mitigations for this requirement should be addressed via contractual mechanisms and policy considerations.

Practical Example: Not being able to trust cloud operators fully is one of the primary reasons for the reluctance to adopt cloud services and solutions. Despite this, cloud operators are still hesitant to divulge all their security practices in fear of relinquishing intellectual property. This is problematic for cloud service consumers that have invested significant amount of resources over the past several years (with Sarbanes-Oxley, FISMA, etc.) to gain transparency into their own IT infrastructure.

Importance: For cloud service consumers, it is critical to know the security practices of their cloud operators in order to maintain and improve the security of their data and their IT environment. This means that cloud consumers need to know what their cloud operators are doing and if their cloud operators are effectively performing those functions. In addition, cloud consumers must be able to verify their cloud operators' practices randomly and independently.

Solution Maturity: Security control frameworks exist (such as CoBIT, ISO 27000, NIST SP 800-53, etc.) in order to design and assess the security posture of an organization. NIST-validated, SCAP-compliant tools exist to identify and verify vulnerability and configuration data, and virtualization management modules also exist to provide additional insight into the virtual infrastructure. The shift that may need to occur is tailoring the frameworks and the technology for the cloud and a cultural shift to provide the needed transparency.

Mitigation 1: Operator human resources practices

Through standard and effective SLAs, consumers can specify background screening requirements for operator staff hiring, and can require regular training so that operator employees (including contractors and third-party users) understand their responsibilities and use best practices. Consumers and operators can also agree to apply separation of duties and to monitor unauthorized activities by malicious insiders.

Sufficiency Comment: There is still a need to develop and adopt consistent SLAs of high quality and completeness for cloud services.

Mitigation 2: Operator self-certification and third-party verification

To gain consumer's trust, cloud operators should seek self-certification of compliance with legal and regulatory requirements (for example, SAS 70- or ISO 27002-compliant). There is also a significant increase in third-party independent audit of the operator's information security management from policies all the way to specific controls.

Sufficiency Comment: A consumer still needs to verify if specific requirements for security are met by the operator and how operator's measures compare.

Mitigation 3: Operator transparency

Operator's transparency ensures building the necessary trust that consumers need to verify that cloud operators will offer the appropriate level of security and governance for their data and applications. And operator transparency embodies a commitment to communicate security information (policies, practices, and incident responses) to consumers and to advise them as to risks and risk mitigations.

Sufficiency Comment: For more details, refer to the section *Lack of Visibility for Customers* of this document.

Mitigation 4: Reviews from other consumers and industry groups can serve as a useful resource for research on the services offered and the general reputation of cloud providers. However, one should remain mindful that much of the information that may be available online may be subjective or unreliable; therefore careful consideration should be taken.

Sufficiency Comment: Potentially reliable but is still a rapidly expanding online resource.

References:

- ISO 27000
- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*,[31] Revision 3
- FedRAMP repository of authorized cloud providers (http://www.fedramp.gov).
- Reviews and insights into the very best cloud hosting companies (http://www.cloud-hosting-providers.com/).
- List of top cloud servers (http://www.bestcloudserver.com/).
- List of top cloud hosting providers (http://www.cloudhostingreviewer.com/).

1.8 Business Continuity and Disaster Recovery

Description: This requirement discusses the need for business continuity and disaster recovery in the cloud computing ecosystem. Even in traditional IT operations, business continuity planning (more specifically, contingency planning) is complex, and the effectiveness of its implementation is difficult to test and verify. More often than not, when disasters occur, unexpected disruptions create confusion and result in less efficient recovery practices. Cloud computing adds more complexity to IT infrastructure and obfuscates responsibilities between cloud provider and customer. There is an elevated concern of business continuity and disaster recovery in this new paradigm.

Technical Considerations: The migration of a service or application to a cloud environment may provide some inherent level of redundancy. Cloud providers are required to supply documented Disaster Recovery (DR) and Continuity of Operations (COOP) plans as a deliverable of their FedRAMP submission package.

Practical Example: As pointed out in the NIST SP 800-144, *Guidelines on Security and Privacy in Public Cloud Computing*[32], Section 4.8: *Availability*, outages due to high-level disruptions occur in cloud computing services despite redundant architectures designed for high availability. In addition, the value concentration in clouds makes them the preferred targets of malicious attacks. Consequently, it is important to plan and implement business continuity and disaster recovery in consideration of the characteristics of cloud computing:

The intricate business relationship and managerial responsibility (ownership and governance) in cloud computing complicate business continuity planning and implementation and effective disaster recovery.

The large scale, complexity, and dynamics of cloud infrastructure make it even more difficult for maintaining business continuity and performing disaster recovery.

[31] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf
[32] http://csrc.nist.gov/publications/nistpubs/800-144/SP800-144.pdf

Commingled data and services result in commingled responsibilities and contingency plans.

Clustering, quick provisioning and on-demand self-service provide conduits for disruptions to propagate through the cloud environment.

However, economies of scale in cloud computing have the potential to provide a full range of backup sites and to carry out effective testing and exercises in order to validate security controls of contingency planning.

Importance: Identifying an effective Contingency and Disaster Recovery Plan is imperative to securing information systems and is a required deliverable of the Risk Management Framework and Certification and Accreditation Process.

Solution Maturity: Documented security policies and procedures, clustering technologies, alternate sites, and backup have all been used in traditional IT contingency planning and implementation. How effective they are in cloud computing (with order of magnitude increase in scale, complexity, and dynamics) remains to be seen. Clear roles and responsibilities and close collaboration between the cloud provider and the cloud customer are necessary for any effective business continuity and disaster recovery. It is also necessary to coordinate incident activities with contingency planning activities between cloud provider and customer.

Mitigation 1: Consistent Policies and Procedures

Consumers should develop a contingency plan for a cloud-based application or system using the guidelines in NIST SP 800-34, *Contingency Planning Guide for Federal Information Systems*,[33] Rev 1, and in Domain 9: *Contingency Planning, Federal Cloud Security Guidelines* (Draft V 0.10 or latest).

The policies and procedures should consistently address, at a minimum, the following aspects:

- Determine ownership, data sensitivity, cloud service and deployment models, roles and responsibilities.
- Specify Recovery Point Objective (RPO) and Recovery Time Objective (RTO).
- Set recovery priorities and map resource requirements accordingly.
- Provide a road map of actions for activation, notification, recovery procedures, and reconstitution.
- Enforce policies and procedures through SLAs.
- Incorporate customer's contingency plan for individual application and/or system into cloud provider's overall contingency plan.

[33] http://csrc.nist.gov/publications/nistpubs/800-34-rev1/sp800-34-rev1_errata-Nov11-2010.pdf

- Establish management succession and escalation procedures between cloud provider and customer.
- Reduce the complexity of the recovery effort.

Sufficiency Comment: To be effective, this mitigation needs unprecedented close collaboration between cloud provider and cloud consumer. Since recovery priorities are based on mission requirements and data sensitivity, applications should be partitioned according to data sensitivity as suggested in mitigations of multi-tenancy.

Mitigation 2: Clustering and redundancy

Clustering and data redundancy could mitigate the risk of disasters by facilitating business continuity and disaster recovery. The mitigation calls for the use and implementation of:

- Shared storage clusters;
- Hardware-level clustering;
- VM clusters; and
- Software clustering (application servers and database management systems).

Sufficiency Comment: The key to clustering security is isolation (logical separation), and its sufficiency is addressed in the mitigations of multi-tenancy.

Mitigation 3: Alternate sites and backup

NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*,[34] Revision 3, defines the security controls for the information and information systems. To mitigate the risk of disaster, consumers should use best practices, such as:

- Use alternate storage and processing sites.
- Use alternate telecommunication services.
- Ensure information system backup.
- Provide cold, warm and hot backup sites (economies of scale).
- Outsource information system backup to a cloud backup service.
- Use multiple cloud providers.
- Supplement cloud provider's backup schemes with customer's non-cloud sites.

Sufficiency Comment: A hot backup is a preferred solution to down time for high-available systems, but may be expensive.

Mitigation 4: Effective testing and exercises of the contingency plan

The consumer should test and exercise the contingency plan periodically to verify its effectiveness (including revision of the personnel training) and to asses if its update reflect

[34] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf

recent changes. The contingency plan testing and exercises should be done in production-like testing environments against high level disruptions to discover deep-rooted risks.

Sufficiency Comment: Agencies are constrained to simulate level 3 and 4 disruptions in their core production environments. There are resource limitations to provide production-like testing environments and as a result, contingency plan testing and exercises are usually tabletop scenario exercises or at best consist of some failovers in peripheral equipment.

References:

- NIST SP 800-34, *Contingency Planning Guide for Federal Information Systems*, Rev 1
- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3
- NIST SP 800-144, *Guidelines on Security and Privacy in Public Cloud Computing*
- Federal Cloud Security Guidelines (2011)

1.9 Technical Continuous Monitoring Capabilities

Description: This security requirement identifies the lack of technical continuous monitoring capabilities necessary to support cloud environments. This need can be especially challenging with multi-data center clouds using many different security tools. The audit data from diverse security tools must be normalized and aggregated to provide situational awareness to support low-level security operations. This data then needs to be further aggregated to support higher-level operational pictures and management decisions. The data needs to also reflect both the security posture of the cloud and the security posture of the customer's use of the cloud.

Practical Example: Currently, questions remain regarding how specific information regarding the security posture of the environment in which a particular subscribers data may reside, is monitored, aggregated, and processed. Current monitoring solutions were not designed for highly mobile environments or multi-tenant environments with potentially largely disparate monitoring and reporting requirements.

Importance: For cloud providers, it is critical that they be able to gain situational awareness of their cloud environment and to provide evidence to their customers that the cloud infrastructure is secure. It also may be important to provide customers feedback on the security of their use of the cloud.

Solution Maturity: Much of the foundation for eliminating this impediment exists in the area of security automation standards. This is especially true for asset, configuration, and vulnerability management. However, the higher-level model for providing situational awareness is still in the draft stages.

Mitigation 1: The CAESARS Framework Extension[35] effort

The CAESARS Framework Extension is a joint NIST, National Security Agency, and DHS effort that provides a reference model for data normalization, aggregation, and situational awareness. In the short term, it is focused on binding to the Security Content Automation Protocol to provide continuous monitoring capabilities for asset, configuration, and vulnerability management.

CyberScope is a secure web-based application requiring two-factor authentication that collects both automated and manual data from federal agencies; this is used to assess and report on the agencies' IT security posture. CyberScope receives both live data feeds and data entry by agency staff. It is designed as a central repository, which agencies can access through a standard interface and format. Through this interface, agencies provide data to OMB, which then compiles and generates reports to other agencies, as required by FISMA.[36]

The types of information that OMB requires to be reported through CyberScope are broader in scope than the status of individual assets, which are the focus of the CAESARS reference architecture. Nevertheless, the CAESARS reference architecture can directly support the achievement of some of the OMB objectives by ensuring that the inventory, configuration, and vulnerabilities of systems, services, hardware, and software are consistent, accurate, and complete. A fundamental underpinning of both the CAESARS reference architecture and the OMB reporting objectives is full situational awareness of all agency IT assets.[37]

Sufficiency Comment: Once adopted and implemented, the CEASARS Framework will allow agencies to implement continuous monitoring more rapidly by leveraging continuous monitoring-compliant tools and therefore eliminating the need for custom integration efforts.

References:

- CAESARS Framework Extension: *A Continuous Monitoring Technical Reference Architecture*, Draft NIST IR 7756, http://csrc.nist.gov/publications/drafts/nistir-7756/Draft-NISTIR-7756_second-public-draft.pdf

[35] http://csrc.nist.gov/publications/drafts/nistir-7756/Draft-nistir-7756_feb2011.pdf
[36] https://www.cippguide.org/2010/11/02/cyberscope/
[37] http://www.dhs.gov/xlibrary/assets/fns-caesars.pdf

Technically Oriented Security Requirements

The issues are amenable to automated mitigation mechanisms or require technical development and/or research for mitigating solutions.

1.10 Visibility for Consumers

Description: This security requirement discusses the fact that cloud consumers have very limited visibility into the provider's security measures and the related incident alert and audit information with respect to cloud resources and customer's data and applications. Most of this information is used internally by cloud providers that are reluctant to share it in fear of divulging proprietary information and introducing an avenue of attack. Serious questions remain unanswered:

- How can cloud customers observe their workloads, and monitor their security, privacy, compliance, system's health, and general status?
- How can customers instruct the cloud providers as to what kind of information they are interested in?

Technical Considerations: Technically, what was once a rack of physical machines interconnected via a network switch may be transformed in the cloud into a single virtual machine that hosts many applications and a virtual switch that enables communication with other virtual machines. Movement of virtual machines within the same physical host-machine or to different hosts with different geo-location (e.g., different data centers in the same country or abroad) may occur dynamically, making monitoring and management of virtual machines much more complex. The prevalent monitoring and management tools are mostly piecemeal and specific to each provider. To achieve the needed level of transparency in the cloud, there are needs and undertakings for unified tools that deeply monitor network, computer, storage resources, and their virtual counterparts and broadly manage provisioning, configuration, change control, and compliance.

Importance: Cloud customers are ultimately liable for security and privacy of their information and cloud-based information systems. Specifically, security, privacy, and compliance regulations state that the liability cannot be outsourced, and cloud providers do not take on full responsibility for security in their SLAs. Cloud providers usually compensate for the subscription cost of an outage, but not for the actual damage or loss of business or data. Customers seeking confidence in the cloud will favor cloud providers that can build high visibility and provide greater transparency (refer to NIST SP 800-144, *Guidelines on Security*

and Privacy in Public Cloud Computing[38] and SP 800-146, *Cloud Computing Synopsis and Recommendations*[39] [Draft]).

Solution Maturity: Monitoring and management tools are currently being unified to be more effective in the cloud environment. There are also efforts ongoing for multi-cloud mash-up (e.g., Web 2.0-based). Standards are maturing for alert exchange, and are emerging for customer information personalization requests from the cloud (e.g., Cloud Audit).

Mitigation 1: Agreement and cooperation between providers and consumers to implement customized controls based on consumer-specific requirements and to provide transparency to their implementation and use.

As pointed out in the FedRAMP's *Considerations for Federal Cloud Computing Audit and Risk Assessment*, SLAs should identify customer-specific requirements and clearly state who is responsible for what monitoring and audit task (to prevent visibility gap between provider and customer) and who is informed of the results. Additionally, standards and methods should be specified for customers to instruct the cloud as to what to monitor and to be alerted about.

Sufficiency Comment: Still in debate is the appropriate level of abstraction and summarization of monitoring and audit results that protect provider's sensitive information and satisfies the customer's needs for transparency.

Mitigation 2: Effective Monitoring

Consumers can achieve greater visibility with an effective monitoring system that includes:

- Packet-based, strategically deployed among physical and virtual machines, real-time monitoring and historical trending metrics;
- End-to-end monitoring and measurement handled by cloud applications and embedded in the cloud architecture using cloud application programming interfaces (APIs);
- Centralized monitoring and analysis system of configuration files and log files, with automatic alert capability; and
- SCAP-compliant monitoring tools. SCAP is an alert format standard mandated by the U.S. Government and which can help providers push alerts to consumers in a standard format.

Sufficiency Comment: Once fully standardized and faithfully implemented, this may be sufficient. Sufficiency depends strongly on the kinds of monitoring the cloud providers will support.

Mitigation 3: Audit

CloudAudit.org is a Cloud Security Alliance (CSA) standardization initiative to provide a common interface and namespace (mostly through mapping) that allows providers to automate

[38] http://csrc.nist.gov/publications/drafts/800-144/Draft-SP-800-144_cloud-computing.pdf
[39] http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

the Audit, Assertion, Assessment, and Assurance (A6) of their cloud environments and allows customers to do likewise via open, extensible, and secure APIs.

Sufficiency Comment: It is still evolving at this stage (unclear whether there are actual implementations to date).

Mitigation 4: Unified monitoring and management tools

- Unified and centralized tools that monitor and manage both physical and virtual environments and can be accessed by both administrators and customers (e.g., EMC Ionix and VMware vCenter); and
- Tools that push monitoring to customers and allow customers to configure what's interesting to them (e.g., Amazon CloudWatch).

Sufficiency Comment: Once multiple clouds are involved, there is a strong need for flexible ways to further unify monitoring and management tools.

References:

- Cloud Security Alliance, www.cloudaudit.org
- Security Content Automation Protocol (SCAP), http://scap.nist.gov
- http://aws.amazon.com/cloudwatch/
- http://symmetrix.com/products/detail/software/ionix-unified-infrastructure-manager.htm
- NIST SP 800-144, *Guidelines on Security and Privacy in Public Cloud Computing*
- NIST SP 800-146, *Draft Cloud Computing Synopsis and Recommendations*[40]
- FedRAMP's *Considerations for Federal Cloud Computing Audit and Risk Assessment*

1.11 Control for Consumers

Description: Today, customers have very limited control over security policies enforced by cloud providers on their behalf. There is also very little automation available to help customers to implement technical controls (policies) across their cloud applications. Questions are raised:

- How can cloud customers maintain effective control over their workloads even though the protection mechanisms and the locations of workloads may not be known to them?
- How can customers instruct cloud providers as to what kind of security policies they want to be enforced at various control layers such as data object, VMs/Applications, virtual network, and geographic location?

Importance: Moving IT to cloud necessitates some relinquishing of control over how information is protected and where it resides. It is important to identify information assets and control needs and to adopt cloud models accordingly. Further, customers and providers need to be able to define and enforce security policies at various control layers in consideration of:

[40] http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

- Much of the security policies are specific to customers, not providers. In other words, the policies depend on the specifics of customer business, business processes, regulations, standards, etc.
- Providers cannot independently know and enforce security requirements because these requirements are customer-specific.
- There are no/few tools available for customers to specify security policies in their terms and to feed them into cloud for control enforcement.
- Available tools are piecemeal and provider-specific, which renders a multi-cloud mash-up unmanageable.

Solution Maturity: Effective controls depend on effective identity and access management (refer to Section 5.5). In addition, fine-grained access control over data objects has long been used in traditional IT and is mature enough to be applied in clouds. Controls at VMs/applications and virtual network layers are provider-specific and less verifiable. Standards such as XACML can be used to instruct access policies across cloud applications, for example, for web services proliferated by Service-Oriented Architecture (SOA), Web 2.0, and cloud. Model-driven security holds promise to integrate dynamic security requirements into cloud through low-level abstraction. Gaining visibility (Section 5.1) and continuous monitoring (Section 4.9) also help to establish customers' confidence of security controls in the cloud.

Mitigation 1: Selection and use of appropriate cloud models

Consumers are responsible for the selection and use of appropriate cloud models. Through the selection process, consumers can ensure that they gain adequate visibility. When selecting the appropriate cloud model, consumers should research and understand:

- Public, hybrid, community, and private cloud models with increasingly greater customer control over tenants;
- SaaS, PaaS and IaaS service models with increasingly greater customer control over infrastructure;
- Externally hosted and internally hosted models with increasingly greater customer control over location; and
- External provider operated, outsourced, and internally operated with increasingly greater customer control over personnel.

Sufficiency Comment: Once the appropriate cloud models are selected based on control needs, customers and providers need to cooperate further to specify and enforce protection mechanisms at various control layers.

Mitigation 2: Control of data objects

By gaining and maintaining ownership and control of data objects, consumers should:

- Establish and maintain data object ownership;
- Use authorization management standards/systems to specify and enforce access controls based on the attributes of the user and the data object, and the context of the access request;
- Keep change history; and
- Manage data life cycle (Section 5.3).

Sufficiency Comment: Access control over data objects is widely used and mature. Customers need to verify that providers protect data at rest, in transit, and especially when it is processed.

Mitigation 3: Control of Virtual Machines, Applications and Networks

Consumers can ascertain the correct implementation of the security controls better when obtaining control of the VMs and existing applications. This process ensures consumers can:

- Perform and verify VM hardening based on federal and/or generally accepted standards;
- Use automated tools to assess and report baseline security configurations and patch updates of VMs (especially long dormant and roll back ones);
- Sanitize and protect virtual machine images;
- Secure the APIs (based on externalized, unified, and fine-grained authorization management, for example) to allocate, start, stop, and de-allocate VMs/applications;
- Apply similar protection mechanisms of physical network (for example, firewall, IDS and antivirus) to intra-host virtual network (vSwitches/vLANs); and
- Make traffic in virtual network visible to security and monitoring devices on physical network.

Sufficiency Comment: Visibility, maturity, and faithfulness of security protection in virtual network are provider-dependent and still evolving.

Mitigation 5: Control of geographic location

Federal cloud consumers may, through SLAs and contract requirements, restrict the geographic location of data due to the potential variances in privacy and security regulations of some jurisdictions. Such restrictions could impose additional burden on providers and potentially impact cost and efficiency.

Sufficiency Comment: Various types of security and privacy regulations and laws at national, state, and local levels make compliance a complicated issue. Cloud providers are at a very early stage in implementing geographic restriction and in achieving right balance between on-demand characteristics and compliance constraints.

References:
www.modeldrivensecurity.org
www.oasis-open.org/committees/tc_home.php?wg_abbrev=xacml

1.12 Data Security

Description: The loss of confidentiality, integrity, or availability of consumer's data can impose a wide variety of impacts. Cloud consumers need to understand the extent of the data protection that a cloud offers (even if limited) so that they can make rational risk-based decisions about when to store data in a cloud. Federal Information Processing Standard (FIPS) 199, *Standards for Security Categorization of Federal Information and Information Systems,*[41] provides a categorization scheme (low-impact, moderate-impact, high-impact) for data and systems and describes the impact in terms of confidentiality, integrity, and availability. The suitability of a cloud to store or process consumer's data varies on the impact level of the data and the assurances that the cloud can offer protection for the data. The technical ability to protect data varies widely depending on how the data is accessed. A number of access scenarios are possible, including:

- **In transit to or from a provider:** Data that a customer wishes to upload into a cloud must be protected in transit; similarly, data that a customer wishes to download from a cloud must be protected in transit.
- **Passively stored with no shared access:** Data that should be accessed only by the originating customer needs to be protected against access attempts by all other entities, while preserving the availability for the originating customer.
- **Passive stored with selective shared access:** Data that should be accessed only by entities that have been authorized by the originating customer for specific access modes (e.g., read, write, delete) needs to be protected against access attempts by unauthorized entities or accesses in unauthorized modes, while preserving availability for authorized customers.
- **Passively stored public access:** Data that should be accessible anonymously in some authorized modes (e.g., read) but that should not be accessed in other modes except by authorized customers.

[41] http://csrc.nist.gov/publications/fips/fips199/FIPS-PUB-199-final.pdf

- **Actively processed:** Data that is accessed by a computation running in a cloud (e.g., a VM, PaaS, or SaaS application) but that otherwise may not be shared or may be shared only selectively.
- **Account termination:** Data that should be maintained for a fixed period of time.
- **Deletion:** The authorized erasure of customer data.

Importance: High. If clouds do not offer usable and robust protection of consumer data, migration to cloud computing will be limited to low-impact data and applications.

Solution Maturity: Immature and evolving.

Mitigation 1: Data management

Data management covers the concepts of ensuring the confidentiality, integrity, and availability of information in transit, being processed, and in storage within the cloud. Another unique aspect of cloud usage is data segregation and isolation, as data from other sources could possibly be commingled. To ensure data confidentiality, encryption of the data with an *approved* or *allowed* cryptographic algorithm listed for encryption/decryption in FIPS 140-2, *Security Requirements for Cryptographic Modules,*[42] (or latest) must be employed. A side benefit of the data encryption, with possible penalty on performance, is the protection against data segregation and commingling. When confidentiality is not necessary, encryption can be avoided in exchange of performance enhancement. However, data integrity is imperative and should be assured by employing an *approved* or *allowed* integrity mechanism listed in the FIPS 140-2 (or latest).

Sufficiency Comment: Methods and techniques for accomplishing encryption, integrity, and availability are evolving. Cloud computing offers unique challenges to encrypting data as it can be at different geo-locations or be in various states.

Several possible data states and how to mitigate data management are listed below:

<u>Data is at rest:</u>

- Prevent tampering of data, copying, altering, or deleting from the original
- Applying hashes or certificates to ensure authenticity
- Method(s) to allow searching and updating encryption algorithms

<u>Data is being processed</u>:

- Treatment of information processed within the cloud
- Processes in place to prevent data leakage

<u>Data is in transit:</u>

[42] http://csrc.nist.gov/publications/fips/fips140-2/fips1402.pdf

- Use of remote VPN connections instead of a public Internet Service Provider (ISP) access
- Use a secure (encrypted) communication when accessed from a mobile wireless devices
- Use of intranet, cross-agency or cross-department
- Protect data using encryption for confidentiality and hashing or signatures for integrity (see *ISIMC Guidelines for Secure Use of Cloud Computing by Federal Departments and Agencies*[43])

Mitigation 2: Employment of a comprehensive Information Life Cycle Management Program

Employing a comprehensive Information Life Cycle Management Program ensures the protection and proper handling of data throughout various phases of data management. The Cloud Security Alliance has developed a useful model of information life cycle management, with phases of Create, Store, Use, Share, Archive, and Destroy[44] (see Figure 2: Information Life Cycle Management Phases). The security requirements in this life cycle are dictated by the types of data.

Figure 2: Information Life Cycle Management Phases

This simple model of Create, Store, Use, Share, Archive, and Destroy can use adapted security controls from NIST SP 800-64, *Security Consideration in the System Development Life Cycle*[45], Revision 2, and NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*[46], Revision 3, but other models in the private sector will be useful for formulating additional pertinent controls.

Sufficiency Comment: The life cycle management approach is proven to be effective in ensuring the proper handling of data. The cloud computing ecosystem introduces additional challenges to the life cycle management model such as data delete and destroy which remain to be addressed in an efficient way.

References:

- http://www.cloudsecurityalliance.org/csaguide.pdf
- NIST SP 800-64, *Security Consideration in the System Development Life Cycle*, Revision 2

[43] http://csrc.nist.gov/groups/SMA/ispab/documents/minutes/2011-07/Jul13_Cloud-Coordinating-Draft-Guidelines-Secure-Use-Cloud-Computing.pdf
[44] http://www.cloudsecurityalliance.org/csaguide.pdf
[45] http://csrc.nist.gov/publications/nistpubs/800-64-Rev2/SP800-64-Revision2.pdf
[46] http://csrc.nist.gov/publications/nistpubs/800-53-Rev3/sp800-53-rev3-final_updated-errata_05-01-2010.pdf

- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3

1.13 Risk of Account Compromise

Description: Benefits of cloud computing include its easy accessibility. A customer can use cloud computing services anywhere with Internet access. However, the Internet is full of threats such as phishing, pharming, and spyware, whose purpose is to steal usernames and passwords (credentials). Facing this Internet security threat environment, customers adopting cloud computing are concerned about how user accounts are protected from hijack to avoid misuse.

Importance: Account hijacking is not new, but its potential is heightened in the context of cloud computing because:

- There is additional attack surface exposure due to increased complexity and dynamics in the infrastructure;
- There are new APIs/interfaces that are less battle-tested;
- A hijacked account may be used to steal information, manipulate data, and defraud others under the customer's identity; and
- A hijacked account may be used to attack other tenants as an insider in the multi-tenancy environment.

Solution Maturity: Mitigations such as strong authentication, encrypted credentials, and secure APIs/interfaces have been used to protect user accounts from hijack. But, as pointed out in the Symantec Security Threat Report, the easiest vulnerability for attackers to exploit is our trust of friends and colleagues. Users tend to click the links and attachments in an email they received from a trusted source (perceived or real). Thus, these mitigations should complement effective user training and proactive monitoring and auditing of unauthorized activities.

Mitigation 1: Strong authentication

Enforcing strong authentication methods for cloud-based services can mitigate the risk of having the consumer's accounts compromised. To do so, the consumer should:

- Enforce a strong authentication method (e.g., strong passwords, token-based keys, biometric authentication) and well-defined authentication policies (e.g., password length and structure, limited password life, etc.);
- Use multifactor authentication;
- Prompt users for their passwords during sessions especially when there are suspicious events; and

- Allow logins coming only from a white-listed address range.

Sufficiency Comment: There is already a password proliferation, resulting in security compromising behavior and increased burden on help desks. Possible considerations in cloud computing include integration with consumers' exiting identity management processes and single sign-on (SSO) systems.

Mitigation 2: Encrypted credentials

Consumers should mitigate risks against attacks that targeting user accounts by:

- Providing a dedicated VPN;
- Using HTTPS and LDAPS;
- Enabling secure cookies; and
- Using strong cryptographic PKI keys.

Sufficiency Comment: The effectiveness of encrypted credentials depends largely on secure key management.

Mitigation 3: Use of National Strategy for Trusted Identities in Cyberspace (NSTIC) mechanisms to efficiently manage the identities while users' privacy is protected.

NSTIC provides the means of creating a secure, trusted *Identity Ecosystem* that is capable of establishing a user-centric privacy protection for any Cloud Ecosystem. The mechanisms employed by an *Identity Ecosystem* are structured in a robust *framework* composed of the overarching set of interoperability standards, risk models, privacy and liability policies, requirements, and accountability mechanisms.

Sufficiency Comment: The framework provided by the National Strategy for Trusted Identities in Cyberspace is effective and interoperable, provides privacy, liability policies, and accountability mechanisms with a user-centric privacy protection architecture that can be easily adopted for cloud computing ecosystems.

Mitigation 4: Secure APIs/interfaces

Consumers should mitigate attacks targeting user accounts by:

- Providing common security models for cloud APIs/interfaces (e.g., WS*, WS-I, SAML for web services); and
- Protecting application security using secure APIs/interfaces (e.g., input validation/escaping/encoding against injection exploits such as SQL injection and cross-site scripting).

Sufficiency Comment: Cloud APIs/interfaces are still evolving (up to the level of cloud federation).

References:

- National Strategy for Trusted Identities in Cyberspace (NSTIC)
- Symantec Internet Security Threat Report, Trends for 2010, Volume 16, April 2011

1.14 Identity Credential and Access Management (ICAM) and Authorization

Description: Unauthorized access to sensitive information in clouds is a major security concern for both customers and providers. Even though identity credential and access management (ICAM) has long been used to manage users and their access to resources in the traditional IT environment, the question is: What kinds of ICAMs in terms of identity proofing, strength of credentials, and access control mechanisms, should be implemented for effective federal cloud-based authentication and authorization?

Technical Considerations: Due to the broad network access characteristic of cloud computing, remote authentication of individual user is a common practice, and it presents a technical challenge to establish the needed level of confidence in user identity commensurate with information sensitivity. In the very dynamic cloud environment, the control of who can access what, where, and when should employ the context-aware enforcement of authorization policies and should be standards-based, scalable, and robust in multi-clouds. Over the years, federal agencies have made a sizable technical investment in ICAM systems in the traditional IT environment. To take full advantage of this investment, agencies would like to see these ICAM systems integrated with the cloud services, especially during the initial adoption stage.

Importance: High. The identity credential and access management should be effective and scalable, especially when multiple clouds are involved. The effectiveness and scalability will be achieved only through the seamless extension of controls from agencies to the cloud. Establishing trust relationships between cloud customers and cloud providers, and, possibly identity, credential and attribute providers, is crucial to the extension of controls.

Solution Maturity: Immature. Although the foundations for solutions exist, practical federal-wide high-assurance ICAM systems are not publicly available yet, especially when suitable for sensitive data in multi-clouds. Currently, agencies are only testing with small projects and less sensitive data.

Mitigation 1: Using provider's ICAM for cloud-based services while keeping agency's ICAM for internal systems.

This is the most straightforward implementation, but there is an initial creation effort of user identities and account provisioning in the cloud.

Sufficiency Comment: The effectiveness depends on how well the provider's ICAM matches the agency's security requirements. There may be duplication of ICAMs and difficulties in

replicating and synchronizing authentication and authorization policies from agency to the cloud. If the provider's ICAM is proprietary and domain-centric, it may encounter difficulties scaling up in multi-clouds.

Mitigation 2: Integrating agency's ICAM with cloud-based services

Cloud providers accept agency-created identity credentials, verify attributes of users and objects through accepted techniques, and enforce authentication and authorization policies in a context-aware fashion.

Sufficiency Comment: The effectiveness depends on how secure an agency's ICAM is integrated into the cloud, especially at endpoints. There may be a need and cost to integrate incompatible ICAMs. It may be difficult to scale up, especially in multi-clouds.

Mitigation 3: Claim-based Federated Identity Management

This is a single sign-on (SSO) solution that an external identity system is dependent upon to give cloud services all the information about the user (claims) along with cryptographic assurance (a security token) that the identity data comes from a trusted source (an issuing authority). Cloud services then make authentication and authorization decisions based on the supplied claims. At present, there are many types of issuing authorities, from domain controllers that issue Kerberos tickets, to Certificate Authorities (CAs) that issue X.509 certificates.

The solution may also use unifying standards such as SAML to exchange authentication and authorization decisions between security domains (for example, identity providers and service providers).

Sufficiency Comment: The effectiveness depends on how trustworthy and secure the issuing authorities and key managements are. Currently, Kerberos systems are mainly used within a security domain, and SAML is mainly binding with web services.

Mitigation 4: Digital Identity

The solution uses the emerging user-centric technologies such as Information Cards (for federal agencies, PIV cards) or OpenID. Rather than centering on a directory (domain-centric), digital identity is focused around the user, enabling users to take their digital IDs to cloud services and to be validated instantly, similar to the way driver's licenses are used in the real world. This solution exhibits the scalability and flexibility needed in multi-clouds.

Sufficiency Comment: The effectiveness depends on how trustworthy the digital identity issuers are and how securely the digital identities are managed. There may be complications when the digital identity is phished, compromised, or simply lost.

Mitigation 5: Standards-based Access Control

No matter what access control model (discretionary access control, mandatory access control, role-based access control, or attribute-based access control) is used, the solution employs emerging standards such as XACML to express and enforce confidentiality and integrity

requirements in a flexible and unifying way for a variety of cloud environments. The flexibility allows an agency to specify and deploy access control policies to match its mixture of assets and business functions, and then to plug in additional policies as business and infrastructure evolve. The unity is meant to express access control policies in a single language and format in multi-clouds.

Sufficiency Comment: XACML needs to be more widely applied beyond web services.

Mitigation 6: Use of National Strategy for Trusted Identities in Cyberspace (NSTIC) mechanisms to manage the identities efficiently while protecting the user's privacy.

NSTIC provides the means of creating a secure, trusted *Identity Ecosystem* that is capable of establishing a user-centric privacy protection for any cloud ecosystem. The mechanisms employed by an *Identity Ecosystem* are structured in a robust framework composed of the overarching set of interoperability standards, risk models, privacy and liability policies, requirements, and accountability mechanisms.

Sufficiency Comment: The framework provided by the National Strategy for Trusted Identities in Cyberspace is effective and interoperable, providing privacy, liability policies, and accountability mechanisms, with a user-centric privacy protection architecture that can be easily adopted for the cloud computing ecosystems.

References:

- XACML http://www.oasis-open.org/committees/download.php/2406/oasis-xacml-1.0.pdf
- DHS Top Security Controls
- OASIS Identity in the Cloud
- SAJACC NIST Cloud Computing Use Cases
- NIST SP 800-63, *Electronic Authentication Guideline*, Revision 1,
- National Strategy for Trusted Identities in Cyberspace (NSTIC)

1.15 Multi-tenancy Risks and Concerns

Description: Cloud computing provides the potential of cost saving through resource sharing. Different tenants use services on the same cloud simultaneously. As a result, there are warranted security concerns:

- A tenant may have access to other tenants' virtual machines, network traffic, actual/residual data, etc.; and
- A tenant may impact the normal operation of other tenants, steal their data, steal their identities, etc.

Importance: Although many network services and programs have simultaneously supported multiple tenants in the past, cloud computing elevates this concern because the resource sharing

is pervasive, exposes many possibly vulnerable interfaces, and potentially occurs at a very large scale. Thus, this is a new challenge, and federal agencies are not familiar with this kind of massive resource sharing and its security ramifications. The uncertainty may impede the adoption of cloud computing. The following mitigations address these concerns by ascertaining application separation and data encryption in cloud computing.

Solution Maturity: Physical separation is a mature enough practice even in traditional IT environments. Despite key management limitations, data encryption has been accepted in eCommerce and federal IT systems. Application partitioning facilitates putting critical components in more secure environments, but its assurance of security needs to be further verified. Logical separation in cloud computing remains a general concern, and its maturity will be vendor-dependent in the near future. Based on their maturity levels, it is suggested to use physical separation or a combination of data encryption, application partitioning, and logical separation (defense in depth) to address the risk of multi-tenancy. All mitigations should complement the identity management and access control best practices.

Mitigation 1: Data encryption

Cloud computing consumers could employ encryption of data in various states to prevent unauthorized data access by co-tenants, such as:

- Data in transit: Encrypt data using a one-time session key similar to how SSL/TLS works.
- Data at rest: Selectively encrypt sensitive data using NIST FIPS 140-2-validated cryptographic algorithms for use in FIPS-mode of operation.
- Manage keys separately from data with higher privileges and preferably accessible only through procedures/programs.
- Change keys periodically and data unencrypted and re-encrypted with the new keys.
- Compile and/or wrap the encryption procedure/program to hide additional data transformation or padding to make it even harder for a snooper to get the key.

Sufficiency Comment: Encryption alone is not sufficient to mitigate the risks from multi-tenancy. Encrypted data is not as vulnerable to disclosure as plaintext data but is still vulnerable to loss and possibly corruption. Key management must be performed correctly and at scale, or the cryptography does not provide value. Performance may be affected.

Mitigation 2: Application Partitioning

Application partitioning can ensure:

- Separate access control functionality from business processing functionality;

- Separate logic processing functionality from data access functionality;
- Separate user functionality from system management functionality; and
- Aggregate functionalities with similar security requirements to run in the same virtual environment and take advantage of modern compartmentalized data centers (vLANs/sub-network zones with varying levels of security controls).

Sufficiency Comment: As a single strategy, localization is not sufficient to mitigate the risks from multi-tenancy but it can localize the reach of security risks and hence reduce risks.

Mitigation 3: Logical separation

The support of holistic logical separation of the resources at all the layers: computing (virtualization), networking (vSwitches and vLANs), and storage (logical separation of files with access controls) can mitigate against the risks associated with multi-tenancy in the cloud.

Implementing logical separation mechanisms also requires:

- Securing the virtualization server (hypervisor isolation settings to limit accesses);
- Securing the virtual network by working hand-in-hand with the physical network security, especially against man in the middle attacks (MAC spoofing and ARP poisoning); and
- Hardening the Virtual Machine (VM) so that the virtualization layer is not exposed to attack.

Sufficiency Comment: If logical separation is faithfully implemented, it addresses much of the multi-tenancy impediment. The difficulty is in achieving assurance that an implementation is correct.

Mitigation 4: Physical separation

The risks associated with the multi-tenancy could also be mitigated through physical separation, which can be provisioned to consumers with special security requirements and which implies the use of special virtual environments with physical separation of the full-stack cloud infrastructure.

Sufficiency Comment: For additional isolation and separation, when a physical separation is not satisfactory, a private cloud environment can be used.

References:

- NIST SP 800-146, *Cloud Computing Synopsis and Recommendations* (Draft)- http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

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- Top Threats to Cloud Computing V1.0 - https://cloudsecurityalliance.org/topthreats/csathreats.v1.0.pdf
- SaaS, PaaS, and IaaS: a Security Checklist for Cloud Models - http://www.csoonline.com/article/print/660065
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1.16 Cloud-Based Denial of Service

Description: Despite clauses in SLAs that imply high availability and minimal downtimes for subscribers, service or utility outages remain possible due to man-made causes (e.g., malicious attacks or inadvertent administrator errors) or natural causes (e.g., floods, tornados, etc.). Denial of Service (DoS) attacks have existed since the early days of network computing, but cloud computing has significantly increased the attack surface.

Importance: Internally accessed applications become remotely accessible as cloud services, thus exposed to DoS attacks. Due to multi-tenancy, DoS attacks may be launched by insiders through shared resources, for example, via side channel attacks. Malicious users can initiate distributed DoS using the vast resources of cloud to the level of severity never seen before. It is important to address DoS issues in the cloud environment.

Solution Maturity: One prevalent solution to withstand DoS attacks is to provide diversity and redundancy in networking and data processing and to use multiple cloud service providers (refer to Section 4.8, Business Continuity and Disaster Recovery). Another traditional solution still beneficial in the cloud environment is to use modern network devices that recognize DoS signatures and prevent DoS traffic. However, the separation and isolation mechanisms in cloud to protect against inside DoS attacks are still evolving and vendor-dependent (refer to Section 5.6, Risk from Multi-tenancy). Finally, cloud computing depends on strong identity credential and access management (ICAM) to keep malicious users at bay (refer to Section 5.5, Identity Credential and Access Management (ICAM) and Authorization not Deployed).

Mitigation 1: Hybrid cloud-based solution involving two or more cloud providers

The consumers can adopt one of the hybrid cloud models described in the NIST SP 500-292, *Cloud Computing Reference Architecture,*[47] such as:

- Cloud consumer adopts hybrid approach with cloud broker to contract with two or more cloud providers (cloud broker service aggregation); or
- Cloud provider adopts hybrid approach by contracting with two or more cloud carriers for access network to cloud consumer(s).

NIST Cloud Computing Standards Roadmap – the eighth scenario discusses cloud consumer access across multiple clouds, simultaneously, as a mitigation strategy.

Deployment Case 2: In the distributed deployment cases, a single cloud consumer has an application that may be distributed across two or more cloud providers and administrative domains simultaneously. While the cloud consumer may have simple consumer-provider interactions with their application and the providers, more complicated Peer-to-Peer ("P2P") interactions may be required -- between both the consumer and provider and also between the providers themselves.

Sufficiency Comment: See usage scenario one of the NIST SP 500-292, *Cloud Computing Reference Architecture.*[48] An outage experienced by one cloud provider will not result in total loss of cloud consumer access to cloud-based data unless the second cloud provider experiences an outage as well. A cloud provider connected to two cloud carriers provides redundant paths. An outage experienced by one cloud carrier will not result in total loss of cloud provider access to cloud consumers. This solution will require the development of interoperability standards and contractual relationships between cloud providers. Also more research is required into the effects of these mitigation strategies on the cloud-based risk for the cloud consumer.

Mitigation 2: Cloud consumer contracts cloud carrier (or cloud broker) for diverse network access from customer site(s) to the cloud carrier network. Cloud consumer site(s) access diversity can take the form of ingress/egress, route, or switch, serving wire center and interconnection points (cloud broker service intermediation).

Cloud provider must provide a highly redundant, high-availability service, resource abstract, and control physical resource layers (NIST SP 500-292, *Cloud Computing Reference Architecture*[49]). These three layers are all required to provide a cloud service to cloud

[47] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf
[48] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf
[49] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf

consumers within the cloud provider boundary. Cloud provider must be required to have COOP/DR plans in place by cloud customer contract and/or SLA.

Sufficiency Comment: See usage scenario number one of NIST SP 500-292, *Cloud Computing Reference Architecture.*[50] Network diversity between the cloud consumer site(s) and cloud carrier points of presence is a sound strategy to address the risk of denial of service (DoS).

The physical building and the three layers (service, resource, and physical) must be redundant, resilient, and fault resistant. Additional measures are described in NIST SP 800-146, *Draft Cloud Computing Synopsis and Recommendations,*[51] *which* suggests the following mitigation strategies:

- SLA Evaluation;
- Portability of Workloads;
- Interoperability between Cloud Providers; and
- Disaster Recovery.

Mitigation 3: Cloud consumer contracts with a cloud carrier, or cloud broker, for redundant customer premises equipment (CPE) with failover (FO) capability to provide high-availability network access to complement diverse network access to cloud provider network. Cloud provider must provide redundant data instances (protect data availability) through various strategies and control measures.

Sufficiency Comment: See usage scenario one of the NIST RA (2011). The cloud carrier, through its transport agent for example, should provide required equipment as part of the cloud-based service contract with the appropriate SLA. The equipment SLA includes provisions such as: equipment monitoring, service, upgrades, repair, replacement, and technology refresh.

In the Cloud Security Alliance, *The Cloud Control Matrix*: Control Area: Operations Management - Equipment Maintenance Policies and Procedures, it states that it is established for equipment maintenance ensuring continuity and availability of operations:

- MA-2 Controlled Maintenance
- MA-3 Maintenance Tools
- MA-4 Non-Local Maintenance
- MA-5 Maintenance Personnel

[50] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf
[51] http://csrc.nist.gov/publications/drafts/800-146/Draft-NIST-SP800-146.pdf

- MA-6 Timely Maintenance

References:

- Cloud Security Alliance, *The Cloud Control Matrix*
- Federal Risk and Authorization Management Program (FedRAMP)
- NIST SP 500-291, *Cloud Computing Standards Roadmap*[52]
- NIST SP 500-292, *Cloud Computing Reference Architecture*[53]
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume 1, High-Priority Requirements to Further USG Agency Cloud Computing Adoption*[54] (Draft)
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume II, Useful Information for Cloud Adopters*[55] (Draft)
- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume III, Technical Considerations for USG Cloud Computing Deployment Decisions* (Draft)
- NIST SP 800-53, *Recommended Security Controls for Federal Information Systems and Organizations*, Revision 3

1.17 Incident Response

Description: Incident response and computer forensics in a cloud environment require fundamentally different tools, techniques, and training to assess a situation and capture appropriate evidence accurately when conducting an incident response that follows federal incident response guidelines. The response plan should address the possibility that incidents, including privacy breaches and classified spills, may impact the cloud and shared cloud customers.

Importance: This requirement highlights the need for updated guidance and procedures to comply with federal incident response and reporting requirements and mission operational needs in a cloud environment.

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[52] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/StandardsRoadmap/NIST_SP_500-291_Jul5A.pdf

[53] http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/ReferenceArchitectureTaxonomy/NIST_SP_500-292_-_090611.pdf

[54] http://www.nist.gov/itl/cloud/upload/SP_500_293_volumeI-2.pdf

[55] http://www.nist.gov/itl/cloud/upload/SP_500_293_volumeII.pdf

Mitigation: Cloud providers are required to develop and provide a documented incident response plan, as a deliverable included in their FedRAMP authorization package submission, that is consistent with existing federal guidance and the robust NIST four-phase incident handling guide, NIST SP 800-61, *Computer Security Incident Handling Guide*. This incident response life cycle consist of Preparation; Detection and Analysis; Containment, Eradication, and Recovery; and Post-Incident Activity.[56]

Figure 3: NIST Incident Response Life Cycle

A cloud computing-oriented architecture introduces a number of complexities when conducting the incident response life cycle, though the steps of the life cycle remain the same.

The procedures cloud providers should use to implement FISMA requirements are found in two primary documents: NIST Special Publication 800-61, *Computer Security Incident Handling Guide*; [57] and the Concept of Operations for the United States Computer Emergency Readiness Team (US-CERT), the federal security incident-handling center located within the Department of Homeland Security.[58]

Cloud providers develop FedRAMP package deliverables based on standard requirements for security based on SP 800-53 controls, federal policy and guidance, and best practices. If a federal subscriber has additional requirements that must be met, SLAs should be created to ensure that those additional requirements are specifically addressed.

Technical Considerations: The technical considerations of responding to an incident in a cloud environment are significantly different than traditional incident response and forensic

[56] NIST SP 800-61, Computer Security Incident Handling Guide, http://csrc.nist.gov/publications/nistpubs/800-61-rev1/SP800-61rev1.pdf

[57] See *Computer Security Incident Handling Guide: Recommendations of the National Institute of Standards and Technology* (http://csrc.nist.gov/publications/nistpubs/800-61/sp800-61.pdf).

[58] The responsibilities of US-CERT are outlined in 44 U.S.C. § 3546. Its complete set of operating procedures may be found on the US-CERT website *at* www.us-cert.gov/federal/reportingRequirements.html.

techniques, though the elemental guidelines still apply. NIST identifies the forensic process in SP 800-86, which is applicable in a cloud environment.[59]

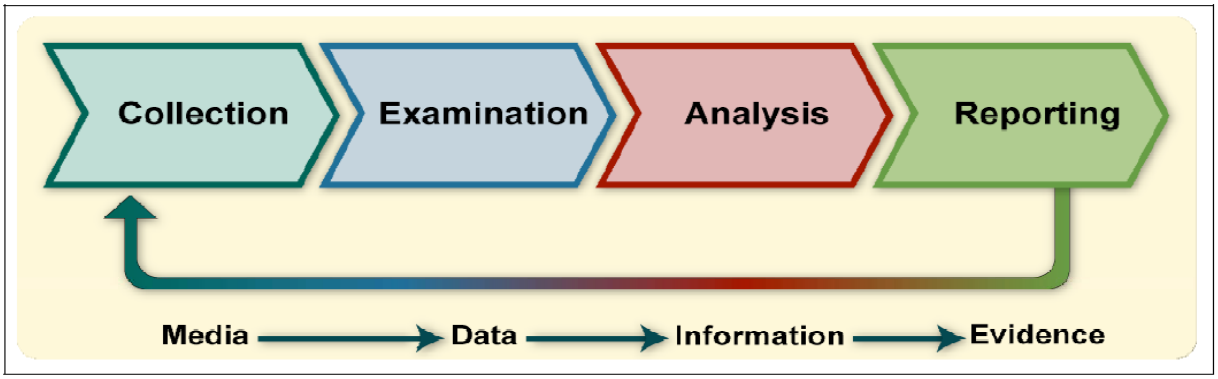

Figure 4: The Forensic Process

Organizations should track security incidents and privacy complaints related to cloud computing for purposes of internal and external reporting and the evaluation of provider performance. This information should also be used to identify areas within an organization that may require further review or education and training.

[59] NIST SP 800-86: *Guide to Integrating Forensic Techniques into Incident Response*, August 2006.

Glossary and Acronyms

A&A: Assessment and Authorization

Assessment: In this context, the process by which a third-party assessment organization generates a security assessment package for review.

Authorization: In this context, the process by which the FedRAMP Joint Authorization Board (JAB) reviews the security assessment package based on a prioritized approach and decides on a grant of provisional authorization. http://www.fedramp.gov/

CA: Certificate Authority

C&A: Certification and Accreditation – terminology replaced by "Assessment and Authorization"

Chain of custody: The seizure, custody, control, transfer, analysis, and disposition of physical or electronic evidence.

CPE: Customer Premises Equipment

Cloud Auditor: See NIST SP-500-292 Reference Architecture.

Cloud Broker: See NIST SP-500-292 Reference Architecture.

Cloud Consumer: See NIST SP-500-292 Reference Architecture.

Cloud Carrier: See NIST SP-500-292 Reference Architecture.

Cloud Provider: See NIST SP-500-292 Reference Architecture.

Contingency and Disaster Recovery Plan (CDRP): A plan that describes how an organization is to deal with potential disasters - sometimes referred to as a business continuity plan (BCP) or a business process contingency plan (BPCP).

Data Protection: In order to ensure consistency with the global use of the term, for the purpose of this document, the term is used to mean "privacy."

E-discovery: Electronic Discovery

Evidential weight: The degree of completeness of the information upon which a probability is based.

FedRAMP:	The Federal Risk and Authorization Management Program – see http://www.fedramp.gov/.
FISMA:	Federal Information Security Management Act – see http://www.nist.gov/itl/csd/sma/fisma.cfm.
FIPS:	Federal Information Processing Standard- see http://www.nist.gov/itl/fips.cfm.
GSA:	General Service Administration- see http://www.gsa.gov.
Hypervisor:	One of many hardware virtualization techniques allowing multiple operating systems to run concurrently on a host computer (also called Virtual Machine Manager [VMM]).
ICAM:	Identity, Credential, and Access Management
IaaS:	Infrastructure as a Service – see NIST SP 500-292.
Multi-tenancy:	The concept of cloud consumers sharing both virtualized infrastructure and application servers. In multi-tenant cloud architectures, database and application servers are typically shared to reduce the cost to consumers, but with sharing resources and co-location of data come risks to data that must be mitigated.
NSTIC:	National Strategy for Trusted Identities in Cyberspace, see http://www.nist.gov/nstic./
OASIS:	Organization for the Advancement of Structured Information Standards
OpenID:	An open standard that describes how users can be authenticated in a decentralized manner, eliminating the need for services to provide their own authentication systems and allowing users to consolidate their digital identities - see http://openid.net/.
PaaS:	Platform as a Service – see NIST SP 500-292.
SaaS:	Software as a Service – see NIST SP 500-292.

References

- NIST SP 500-291, *Cloud Computing Standards Roadmap* http://collaborate.nist.gov/twiki-cloud-computing/pub/CloudComputing/StandardsRoadmap/NIST_SP_500-291_Jul5A.pdf
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- NIST SP 500-293, *US Government Cloud Computing Technology Roadmap Volume III, Technical Considerations for USG Cloud Computing Deployment Decisions* (Draft)
- NIST SP 800-144, *Guidelines on Security and Privacy in Public Cloud Computing*, http://csrc.nist.gov/publications/nistpubs/800-144/SP800-144.pdf
- NIST SP 800-145, *The NIST Definition of Cloud Computing*, http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf
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Appendix A: Public Security Working Group Collaborating Members

The editors of this document would like to thank all members of the NIST Public Cloud Computing Security Working Group that supported our effort. We especially acknowledge the following members[60]:

Margaret Leary, Avaya Government Solutions
Kathleen Lynch, US Air Force / ESC- Jacobs Technology
Paul Sand, The Federal Home Loan Bank of Chicago

[60] A regular member of the NCC SWG that often participated in the meetings, providing feedback during the regular meetings, but did not dedicate the same amount of time a contributor did.