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Cryptographic Algorithms and Key Sizes for Personal Identity Verification

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1. Introduction

The Homeland Security Presidential Directive (HSPD) 12 mandated the creation of new standards for interoperable identity credentials for physical and logical access to Federal government locations and systems. Federal Information Processing Standard 201 (FIPS 201), *Personal Identity Verification (PIV) of Federal Employees and Contractors*, was developed to establish standards for identity credentials [FIPS201]. This document, Special Publication 800-78 (SP 800-78), specifies the cryptographic algorithms and key sizes for PIV systems and is a companion document to FIPS 201.

1.1 Authority

This document has been developed by the National Institute of Standards and Technology (NIST) in furtherance of its statutory responsibilities under the Federal Information Security Management Act (FISMA) of 2002, Public Law 107-347.

NIST is responsible for developing standards and guidelines, including minimum requirements, for providing adequate information security for all agency operations and assets, but such standards and guidelines shall not apply to national security systems. This recommendation is consistent with the requirements of the Office of Management and Budget (OMB) Circular A-130, Section 8b(3), Securing Agency Information Systems, as analyzed in A-130, Appendix IV: Analysis of Key Sections. Supplemental information is provided A-130, Appendix III.

This recommendation has been prepared for use by Federal agencies. It may be used by non-governmental organizations on a voluntary basis and is not subject to copyright. Nothing in this document should be taken to contradict standards and guidelines made mandatory and binding on Federal agencies by the Secretary of Commerce under statutory authority. Nor should this recommendation be interpreted as altering or superseding the existing authorities of the Secretary of Commerce, Director of OMB, or any other Federal official.

1.2 Purpose

FIPS 201 defines requirements for the PIV lifecycle activities including identity proofing, registration, PIV Card issuance, and PIV Card usage. FIPS 201 also defines the structure of an identity credential that includes cryptographic keys. This document contains the technical specifications needed for the mandatory and optional cryptographic keys specified in FIPS 201 as well as the supporting infrastructure specified in FIPS 201 and the related Special Publications 800-73 (SP 800-73), *Interfaces for Personal Identity Verification*, and the forthcoming SP 800-76, *Biometric Data Specification for Personal Identity Verification,* [SP800-76] that rely on cryptographic functions.

1.3 Scope

The scope of this recommendation encompasses the PIV Card, infrastructure components that support issuance and management of the PIV Card, and applications that rely on the credentials supported by the PIV Card to provide security services. The recommendation identifies acceptable symmetric and asymmetric encryption algorithms, digital signature algorithms, and message digest algorithms, and specifies mechanisms to identify the algorithms associated with PIV keys or digital signatures.

Algorithms and key sizes have been selected for consistency with applicable Federal standards and to ensure adequate cryptographic strength for PIV applications. All cryptographic algorithms employed in this specification provide at least 80 bits of security strength. For detailed guidance on the strength of cryptographic algorithms, see the forthcoming [SP800-57], *Recommendation on Key Management*.

1.4 Audience and Assumptions

This document is targeted at Federal agencies and implementers of PIV systems. Readers are assumed to have a working knowledge of cryptography and Public Key Infrastructure (PKI) technology.

1.5 Document Overview

The document is organized as follows:

+ Section 1, *Introduction*, provides the purpose, scope, audience, and assumptions of the document and outlines its structure.
+ Section 2, *Applications of Cryptography in FIPS 201*, identifies the cryptographic mechanisms and objects that employ cryptography as specified in FIPS 201 and its supporting documents.
+ Section 3, *On Card Cryptographic Requirements*, describes the cryptographic requirements for cryptographic keys and authentication information stored on the PIV Card.
+ Section 4, *Certificate Status Information*, describes the cryptographic requirements for status information generated by PKI Certificate Authorities (CAs) and Online Certificate Status Protocol (OCSP) responders.
+ Section 5, *PIV Card Management Keys,* describes the cryptographic requirements for management of information stored on the PIV Card.
+ Appendix A, *Acronyms*, contains the list of acronyms used in this document.
+ Appendix B, *References*, contains the list of documents used as references by this document.

2. Application of Cryptography in FIPS 201

FIPS 201 employs cryptographic mechanisms to authenticate cardholders, secure information stored on the PIV Card, and secure the supporting infrastructure.

FIPS 201 and its supporting documents specify a suite of keys to be stored on the PIV Card for personal identity verification, digital signature generation, and key management. The PIV cryptographic keys specified in FIPS 201 are:

- The asymmetric PIV authentication key;
- A card authentication key, which may be symmetric or asymmetric;
- An asymmetric digital signature key for signing documents and messages; and
- An asymmetric key management key, supporting key establishment or key transport.

The cryptographic algorithms, key sizes, and parameters that may be used for these keys are specified in Section 3.1. PIV Cards must implement private key computations for one or more of the algorithms identified in this section.

Cryptographically protected objects specified in FIPS 201, SP 800-73, and the forthcoming SP 800-76 include:

- The X.509 certificates for each asymmetric key on the PIV Card;
- A digitally signed *Cardholder Unique Identifier* (CHUID);
- Digitally signed biometrics using the Common Biometric Exchange Formats Framework (CBEFF) signature block; and
- The SP 800-73 *Security Object*, which is a digitally signed hash table. [SP800-73]

The cryptographic algorithms, key sizes, and parameters that may be used to protect these objects are specified in Section 3.2. Certificate Authorities (CAs) and card management systems that protect these objects must support one or more of the cryptographic algorithms, key sizes, and parameters specified in Section 3.2.

Applications may be designed to use any or all of the cryptographic keys and objects stored on the PIV Card to authenticate cardholders. Where maximum interoperability is required, applications should support all of the identified algorithms, key sizes, and parameters specified in Section 3.2.

FIPS 201 requires CAs and Online Certificate Status Protocol (OCSP) responders to generate and distribute digitally signed Certificate Revocation Lists (CRLs) and OCSP status messages. These revocation mechanisms support validation of the PIV Card, the PIV cardholder, the cardholder’s digital signature key, and the cardholder’s key management key.

The signed revocation mechanisms specified in FIPS 201 are:

+ X.509 CRLs that specify the status of a group of X.509 certificates; and
+ OCSP status response messages that specify the status of a particular X.509 certificate.

The cryptographic algorithms and key sizes, and parameters that may be used to sign these mechanisms are specified in Section 4. Section 4 also describes rules for encoding the signatures to ensure interoperability.

FIPS 201 permits optional card management operations. These operations may only be performed after the PIV Card authenticates the card management system. Card management systems are authenticated through the use of card management keys. The cryptographic algorithms and key sizes that may be used for these keys are specified in Section 5.

3. On Card Cryptographic Requirements

FIPS 201 identifies a suite of objects that are stored on the PIV Card for use in authentication mechanisms or in other security protocols. These objects may be divided into three classes: cryptographic keys, signed authentication information stored on the PIV Card, and message digests of information stored on the PIV Card. Cryptographic requirements for PIV keys are detailed in Section 3.1. Cryptographic requirements for other stored objects are detailed in Section 3.2.

3.1 PIV Cryptographic Keys

FIPS 201 specifies four different classes of cryptographic keys to be used as credentials by the PIV cardholder:

+ The mandatory PIV authentication key;
+ An optional card authentication key;
+ An optional digital signature key; and
+ An optional key management key.

Table 3-1 establishes specific requirements for cryptographic algorithms and key sizes for each key type. Table 3-1 also specifies two time periods with different sets of acceptable algorithms for each key type. Note that digital signature and key management keys must transition to larger key sizes by 2008, while authentication keys must transition by 2010. This requirement anticipates that digital signature and key management keys will be used to protect data for longer periods of time, while data enciphered with authentication is generally not retained, and should not include private or secret information.

In addition to the key sizes, keys must be generated using secure parameters. Rivest, Shamir, Adleman (RSA) keys must be generated using appropriate exponents, as specified in Table 3-2. Elliptic curve keys must correspond to one of the following recommended curves from [FIPS186-3]:

+ Curve P-224;
+ Curve K-233;
+ Curve B-233;
+ Curve P-256;
+ Curve K-283; *or*
+ Curve B-283.

A PIV Card that supports elliptic curve cryptography must support private key computations for one or more of the listed curves. Applications that rely upon the PIV Card to authenticate users may select which curves to implement based on the community of users.

Note that the NIST recommended curves of 163 and 192 bits in [FIPS186-3] are not supported by this specification. While these curves have equivalent strength with 1024 bit RSA, FIPS 201 implementations supporting elliptic curve should implement algorithms that will still be secure after 2010.[1]

Table 3-1. Algorithm and Key Size Requirements for PIV Key Types

PIV Key Type	Time Period for Use	Algorithms and Key Sizes
PIV Authentication key	Through 12/31/2010	RSA (1024, 2048, or 3072 bits) ECDSA (Recommended Curves, 224 – 283 bits)
	After 12/31/2010	RSA (2048 or 3072 bits) ECDSA (Recommended Curves, 224 – 283 bits)
Card Authentication key	Through 12/31/2010	2TDEA 3TDEA AES-128, AES-192, and AES-256 RSA (1024, 2048, or 3072 bits) ECDSA (Recommended Curves, 224 – 283 bits)
	After 12/31/2010	3TDEA AES-128, AES-192, and AES-256 RSA (2048 or 3072 bits) ECDSA (Recommended Curves, 224 – 283 bits)
Digital Signature key	Through 12/31/2008	RSA (1024, 2048, or 3072 bits) ECDSA (Recommended Curves, 244 – 283 bits)
	After 12/31/2008	RSA (2048 or 3072 bits) ECDSA (Recommended Curves, 224 – 283 bits)
Key Management key	Through 12/31/2008	RSA key transport (1024, 2048, or 3072 bits) ECDH or ECC MQV (Recommended Curves, 224 – 283 bits)
	After 12/31/2008	RSA key transport (2048 or 3072 bits); ECDH or ECC MQV (Recommended Curves, 224 – 283 bits)

This specification also restricts the size of the RSA exponent. Implementations of this specification must choose an exponent greater than or equal to 65,357. Upper bounds for the exponent are based on key length; see Table 3-2 for complete details.

Note that SP 800-73 specifies mechanisms that indicate the algorithm and key size for asymmetric private keys and symmetric secret keys stored on the PIV Card. For elliptic curve keys, these mechanisms also indicate which curve is associated with the private key. The mechanisms specified in SP 800-73 must be used to indicate the algorithm associated with private and secret keys stored on the PIV Card.

[1] Note that 1024 bit RSA is permitted to leverage current products and promote efficient adoption of FIPS 201, but must be phased out by 2010 for authentication keys and 2008 for digital signatures and key management.

Table 3-2. RSA Public Key Exponents

RSA Modulus Size	Minimum exponent	Maximum exponent
1024	65,537 ($2^{16} + 1$)	$2^{864} - 1$
2048	65,537	$2^{1824} - 1$
3072	65,537	$2^{2816} - 1$

This specification requires that the Key Management key must be an RSA key transport key, an Elliptic Curve Diffie-Hellman (ECDH) key, or an elliptic curve Menezes-Qu-Vanstone (MQV) key. The specification for RSA key transport is [PKCS1]; the specification for ECDH and elliptic curve MQV is the forthcoming [SP800-57].

3.2 Authentication Information Stored on the PIV Card

3.2.1 Specification of Digital Signatures on Authentication Information

FIPS 201 requires the use of digital signatures to protect the integrity and authenticity of information stored on the card. FIPS 201 and SP 800-73 require digital signatures on the following objects stored on the PIV Card:

+ The CHUID;
+ Biometric information (e.g., fingerprints);
+ the SP 800-73 Security Object; *and*
+ X.509 public key certificates.

Table 3-3 provides specific guidance for digitally signed information stored on the PIV Card. The first column specifies two time periods; the remaining columns specify public key algorithms and hash algorithms for generating digital signatures. For signatures on the CHUID, 800-73 Security Object, and stored biometrics, the size of the public key and the hash algorithm that must be used to generate the signature is determined by the expiration date of the PIV Card. For X.509 certificates stored on the card, the size of the public key and the hash algorithm used to generate the signature is determined by the expiration date associated with the certificate. Agencies are cautioned that generating digital signatures with SHA-224 and SHA-256 may initially limit interoperability.

Table 3-3. Signature Algorithm and Key Size Requirements for PIV Information

Card or Certificate Expiration Date	Public Key Algorithms and Key Sizes	Hash Algorithms	Padding Scheme
Through 12/31/2010	RSA (1024, 2048, or 3072 bits)	SHA-1 or SHA-256	PKCS #1 v1.5
	RSA (1024, 2048, or 3072 bits)	SHA-256	PSS
	ECDSA (Recommended Curves, 224 – 283 bits)	SHA-1, SHA-224 or SHA-256	N/A
After 12/31/2010	RSA (2048 or 3072 bits)	SHA-256	PKCS #1 v1.5, PSS
	ECDSA (Recommended Curves, 224 – 283 bits)	SHA-1, SHA-224 or SHA-256	N/A

FIPS 201, SP 800-73, and the forthcoming SP 800-76 specify formats for the CHUID, the Security Object, the biometric information, and X.509 public key certificates which rely on object identifiers (OID) to specify which signature algorithm was used to generate the digital signature. The object identifiers specified in Table 3-4, below, must be used in FIPS 201 implementations to identify the signature algorithm. Note that RSA digital signatures may be generated using either the PKCS #1 v.1.5 padding scheme or the Probabilistic Signature Scheme (PSS) padding. Most current implementations of RSA use the padding scheme defined in PKCS #1 v.1.5. The PSS padding scheme OID is independent of the hash algorithm; the hash algorithm is specified as a parameter (for details, see [PKCS1]). Implementations of this specification must use the SHA-256 hash algorithm when generating RSA-PSS signatures. Agencies may wish to transition to the PSS padding scheme as they transition to SHA-256.

Table 3-4. FIPS 201 Signature Algorithm Object Identifiers

Signature Algorithm	Object Identifier
RSA with SHA-1 and PKCS v1.5 padding	sha1WithRSAEncryption ::= {iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) 5}
RSA with SHA-256 and PKCS v1.5 padding	sha256WithRSAEncryption ::= {iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) 11}
RSA with SHA-256 and PSS padding	id-RSASSA-PSS ::= {iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) 10}
ECDSA with SHA-1	Ecdsa-with-SHA1 ::= {iso(1) member-body(2) us(840) ansi-X9-62(10045) signatures(4) 1}
ECDSA with SHA-224	ecdsa-with-SHA224 ::= {iso(1) member-body(2) us(840) ansi-X9-62(10045) signatures(4) ecdsa-with-SHA2(3) 1}
ECDSA with SHA-256	ecdsa-with-SH256 ::= {iso(1) member-body(2) us(840) ansi-X9-62(10045) signatures(4) ecdsa-with-SHA2 (3) 2}

3.2.2 Specification of Public Keys In X.509 Certificates

FIPS 201 requires generation and storage of an X.509 certificate to correspond with each asymmetric private key contained on the PIV Card. X.509 certificates include object identifiers to specify the cryptographic algorithm associated with a public key. Table 3-5, below, specifies the object identifiers that may be used in certificates to indicate the algorithm for a subject public key. Note that symmetric key algorithms are omitted from this table; in these cases there is no need for an X.509 certificate.

Table 3-5. Public Key Object Identifiers for PIV Key Types

PIV Key Type	Asymmetric Algorithm	Object Identifier
PIV Authentication key; Card Authentication key; Digital Signature key	RSA	{iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) 1}
	ECDSA	{iso(1) member-body(2) us(840) ansi-X9-62(10045) id-publicKeyType(2) 1}
Key Management key	RSA	{iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-1(1) 1}
	ECDH or ECC MQV	{iso(1) member-body(2) us(840) ansi-X9-62(10045) id-publicKeyType(2) 1}

Note that a single object identifier is specified in Table 3-5 for all elliptic curve keys. An additional object identifier must be supplied in a parameters field to indicate the elliptic curve associated with the key.[2] Table 3-6 below identifies the named curves and associated OIDs. (RSA exponents are encoded with the modulus in the certificate's subject public key, so the OID is not affected.)

Table 3-6. ECC Parameter Object Identifiers for Approved Curves

Asymmetric Algorithm	Object Identifier
Curve P-224	ansip224r1 ::= { iso(1) identified-organization(3) certicom(132) curve(0) 33 }
Curve K-233	ansit233k1 ::= { iso(1) identified-organization(3) certicom(132) curve(0) 26 }
Curve B-233	ansit233r1 ::= { iso(1) identified-organization(3) certicom(132) curve(0) 27 }
Curve P-256	ansip256r1 ::= { iso(1) member-body(2) us(840) ansi-X9-62(10045) curves(3) prime(1) 7 }
Curve K-283	ansit283k1 ::= { iso(1) identified-organization(3) certicom(132) curve(0) 16 }
Curve B-283	ansit283r1 ::= { iso(1) identified-organization(3) certicom(132) curve(0) 17 }

3.2.3 Specification of Message Digests in the SP 800-73 Security Object

SP 800-73 mandates inclusion of a Security Object consistent with the Authenticity/Integrity Code defined by the International Civil Aviation Organization (ICAO) in [MRTD]. This object contains message digests of other digital information stored on the card (e.g., the cryptographic keys and biometric information) and is digitally signed. Table 3-7 identifies the hash algorithms that may be used to compute the message digests. The set of acceptable algorithms depends upon the expiration date of the PIV Card, since the hash algorithm must protect the data during the entire card lifetime. The Security Object format identifies the hash algorithm used when computing the message digests by inclusion of an object identifier; the appropriate object identifiers are identified in Table 3-8.

[2] Note that the parameters may be specified in the cardholder's public key certificate, or inherited from the issuer's certificate. Regardless of source, the OIDs specified in Table 3-5 apply.

Table 3-7. Hash Algorithm Requirements for the 800-73 Security Object

Card Expiration Date	Algorithm
Through 12/31/2010	SHA-1, SHA-224 or SHA-256
After 12/31/2010	SHA-224 or SHA-256

Table 3-8. Hash Algorithm Object Identifiers for the 800-73 Security Object

Hash Algorithm	Algorithm OID
SHA-1	id-sha1 ::= {iso(1) identified-organization(3) oiw(14) secsig(3) algorithms(2) 26}
SHA-224	id-sha224 ::= {joint-iso-itu-t(2) country(16) us(840) organization(1) gov(101) csor(3) nistalgorithm(4) hashalgs(2) 4}
SHA-256	id-sha256 ::= {joint-iso-itu-t(2) country(16) us(840) organization(1) gov(101) csor(3) nistalgorithm(4) hashalgs(2) 1}

4. Certificate Status Information

The FIPS 201 functional component *PIV Card Issuance and Management Subsystem* generates and distributes status information for PIV asymmetric keys. FIPS 201 mandates two formats for certificate status information:

+ X.509 CRLs; *and*

+ OCSP status response messages.

The CRLs and OCSP status responses are digitally signed to support authentication and integrity.

Table 4-1 below provides specific guidance for digital signatures on PIV status information. For signatures on the CRLs or OCSP status response messages, the size of the public key and the hash algorithm used to generate the signature may be determined by the date the CRL or OCSP message was generated.

Table 4-1. Signature Algorithm and Key Size Requirements for PIV Status Information

CRL or OCSP Response Generation Date	Public Key Algorithms and Key Sizes	Hash Algorithms	Padding Scheme
Through 12/31/2010	RSA (1024, 2048, or 3072 bits)	SHA-1 or SHA-256	PKCS #1 v.1.5
	RSA (1024, 2048, or 3072 bits)	SHA-256	PSS
	ECDSA (Recommended Curves, 224 – 283 bits)	SHA-224 or SHA-256	N/A
After 12/31/2010	RSA (2048 or 3072 bits)	SHA-256	PKCS #1 v.1.5, PSS
	ECDSA (Recommended Curves, 224 – 283 bits)	SHA-224 or SHA-256	N/A

CRLs and OCSP messages rely on object identifiers to specify which signature algorithm was used to generate the digital signature. The algorithms and key sizes specified in Table 3-3 must be used to sign CRLs and OCSP responses. The object identifiers specified in Table 3-4 must be used in CRLs and OCSP messages to identify the signature algorithm.

5. PIV Card Management Keys

PIV Cards may support card activation by the card management system to support card personalization and post-issuance card update. PIV Cards that support card personalization and post-issuance perform a challenge response protocol using a symmetric cryptographic key (i.e., the PIV Card Management Key) to authenticate the card management system. After successful authentication, the card management system can modify information stored the PIV Card. Table 5-1 below, establishes specific requirements for cryptographic algorithms and key sizes for PIV Card Management keys according to the card expiration date.

Table 5-1. Algorithm and Key Size Requirements for Card Management Keys

Card Expiration Date	Algorithm
Through 12/31/2010	2TDEA 3TDEA AES-128, AES-192, and AES-256
After 12/31/2010	3TDEA AES-128, AES-192, and AES-256

Appendix A—Acronyms

The following abbreviations and acronyms are used in this standard:

2TDEA	Two key TDEA
3TDEA	Three key TDEA
AES	Advanced Encryption Standard specified in [FIPS197].
CA	Certificate Authority
CBEFF	Common Biometric Exchange Formats Framework
CHUID	Cardholder Unique Identifier
CRL	Certificate revocation list
ECDSA	Elliptic Curve Digital Signature Algorithm
ECDH	Elliptic Curve Diffie-Hellman Algorithm
ECC MQV	ECC Menezes-Qu-Vanstone Algorithm
FIPS	Federal Information Processing Standard
FISMA	Federal Information Security Management Act
HSPD	Homeland Security Presidential Directive
ICAO	International Civil Aviation Organization
ITL	Information Technology Laboratory
MQV	Menezes-Qu-Vanstone cryptographic algorithm
NIST	National Institute of Standards and Technology
OCSP	Online Certificate Status Protocol
OID	Object Identifier
OMB	Office of Management and Budget
PIV	Personal Identity Verification
PKI	Public Key Infrastructure
PSS	Probabilistic Signature Scheme
RSA	Rivest, Shamir, Adleman cryptographic algorithm
SHA	Secure Hash Algorithm
SP	Special Publication
TDEA	Triple Data Encryption Algorithm; Triple DEA

Appendix B—References

[FIPS186-3] Federal Information Processing Standard 186-3, Digital Signature Standard (DSS), (Revision of FIPS 186-2, June 2000), to be published.

[FIPS197] Federal Information Processing Standard 197, Advanced Encryption Standard (AES), November 2001.

[FIPS201] Federal Information Processing Standard 201, Personal Identity Verification (PIV) of Federal Employees and Contractors, February 2005.

[MRTD] PKI for Machine Readable Travel Documents Offering ICC Read-Only Access Version - 1.1 Date - October 01, 2004. Published by authority of the Secretary General, International Civil Aviation Organization.

[PKCS1] Jonsson, J., and B. Kaliski, "PKCS #1: RSA Cryptography Specifications Version 2.1", RFC 3447, February 2003.

[RFC 3279] Polk, W., Housley, R., and L. Bassham, "Algorithms and Identifiers for the Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation Lists (CRL) Profile", RFC 3279, April 2002.

[SP800-56] Draft NIST Special Publication 800-56, Recommendation on Key Establishment Schemes. (See http://csrc.nist.gov)

[SP800-57] Draft NIST Special Publication 800-57, Recommendation on Key Management. (See http://csrc.nist.gov)

[SP800-67] NIST Special Publication 800-67, Recommendation for Triple Data Encryption Algorithm Block Cipher, May 2004.

[SP800-73] NIST Special Publication 800-73, Interfaces for Personal Identity Verification, April 2005.

[SP800-76] Draft NIST Special Publication 800-76, *Biometric Data Specification for Personal Identity Verification*, February, 2005.