
Stream:	Internet Engineering Task Force (IETF)			
RFC:	9881			
Category:	Standards Track			
Published:	October 2025			
ISSN:	2070-1721			
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RFC 9881

Internet X.509 Public Key Infrastructure -- Algorithm Identifiers for the Module-Lattice-Based Digital Signature Algorithm (ML-DSA)

Abstract

Digital signatures are used within X.509 certificates and Certificate Revocation Lists (CRLs), and to sign messages. This document specifies the conventions for using FIPS 204, the Module-Lattice-Based Digital Signature Algorithm (ML-DSA) in Internet X.509 certificates and CRLs. The conventions for the associated signatures, subject public keys, and private key are also described.

Status of This Memo

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1. Introduction

The Module-Lattice-Based Digital Signature Algorithm (ML-DSA) is a quantum-resistant digital signature scheme standardized by the US National Institute of Standards and Technology (NIST) PQC project [NIST-PQC] in [FIPS204]. This document specifies the use of the ML-DSA in Public Key Infrastructure X.509 (PKIX) certificates and Certificate Revocation Lists (CRLs) at three security levels: ML-DSA-44, ML-DSA-65, and ML-DSA-87.

[FIPS204] defines two variants of ML-DSA: pure and pre-hash. Only the former is specified in this document. See [Section 8.3](#) for the rationale. The pure variant of ML-DSA supports the typical pre-hash flow. Refer to [Appendix D](#) for more details.

Prior to standardization, ML-DSA was known as Dilithium. ML-DSA and Dilithium are not compatible.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Identifiers

The `AlgorithmIdentifier` type is defined in [RFC5912] as follows:

```
AlgorithmIdentifier{ALGORITHM-TYPE, ALGORITHM-TYPE:AlgorithmSet} ::=
  SEQUENCE {
    algorithm  ALGORITHM-TYPE.id({AlgorithmSet}),
    parameters ALGORITHM-TYPE.
               Params({AlgorithmSet}{@algorithm}) OPTIONAL
  }
```

NOTE: The above syntax is from [RFC5912] and is compatible with the 2021 ASN.1 syntax [X680]. See [RFC5280] for the 1988 ASN.1 syntax.

The fields in `AlgorithmIdentifier` have the following meanings:

- `algorithm` identifies the cryptographic algorithm with an object identifier (OID).

- parameters, which are optional, are the associated parameters for the algorithm identifier in the algorithm field.

The NIST-registered OIDs [[CSOR](#)] are:

```
id-ml-dsa-44 OBJECT IDENTIFIER ::= { joint-iso-itu-t(2)
    country(16) us(840) organization(1) gov(101) csor(3)
    nistAlgorithm(4) sigAlgs(3) id-ml-dsa-44(17) }

id-ml-dsa-65 OBJECT IDENTIFIER ::= { joint-iso-itu-t(2)
    country(16) us(840) organization(1) gov(101) csor(3)
    nistAlgorithm(4) sigAlgs(3) id-ml-dsa-65(18) }

id-ml-dsa-87 OBJECT IDENTIFIER ::= { joint-iso-itu-t(2)
    country(16) us(840) organization(1) gov(101) csor(3)
    nistAlgorithm(4) sigAlgs(3) id-ml-dsa-87(19) }
```

The contents of the parameters component for each algorithm **MUST** be absent.

3. ML-DSA Signatures in PKIX

ML-DSA is a digital signature scheme built upon the Fiat-Shamir-with-aborts framework [[Fiat-Shamir](#)]. The security is based upon the hardness of lattice problems over module lattices [[Dilithium](#)]. ML-DSA provides three parameter sets for the NIST PQC security categories 2, 3, and 5.

Signatures are used in a number of different ASN.1 structures. As shown in the ASN.1 representation from [[RFC5280](#)] below, in an X.509 certificate, a signature is encoded with an algorithm identifier in the signatureAlgorithm attribute and a signatureValue attribute that contains the actual signature.

```
Certificate ::= SIGNED{ TBSCertificate }

SIGNED{ToBeSigned} ::= SEQUENCE {
    toBeSigned          ToBeSigned,
    algorithmIdentifier SEQUENCE {
        algorithm       SIGNATURE-ALGORITHM,
                        &id({SignatureAlgorithms}),
        parameters      SIGNATURE-ALGORITHM,
                        &Params({SignatureAlgorithms}
                        {@algorithmIdentifier.algorithm})
                        OPTIONAL
    },
    signature BIT STRING (CONTAINING SIGNATURE-ALGORITHM.&Value(
        {SignatureAlgorithms}
        {@algorithmIdentifier.algorithm}))
}
```

Signatures are also used in the CRL list ASN.1 representation from [RFC5280] below. In an X.509 CRL, a signature is encoded with an algorithm identifier in the `signatureAlgorithm` attribute and a `signatureValue` attribute that contains the actual signature.

```
CertificateList ::= SIGNED{ TBSCertList }
```

The following SIGNATURE-ALGORITHM ASN.1 classes are for ML-DSA-44, ML-DSA-65, and ML-DSA-87:

```
sa-ml-dsa-44 SIGNATURE-ALGORITHM ::= {  
  IDENTIFIER id-ml-dsa-44  
  PARAMS ARE absent  
  PUBLIC-KEYS { pk-ml-dsa-44 }  
  SMIME-CAPS { IDENTIFIED BY id-ml-dsa-44 }  
}  
  
sa-ml-dsa-65 SIGNATURE-ALGORITHM ::= {  
  IDENTIFIER id-ml-dsa-65  
  PARAMS ARE absent  
  PUBLIC-KEYS { pk-ml-dsa-65 }  
  SMIME-CAPS { IDENTIFIED BY id-ml-dsa-65 }  
}  
  
sa-ml-dsa-87 SIGNATURE-ALGORITHM ::= {  
  IDENTIFIER id-ml-dsa-87  
  PARAMS ARE absent  
  PUBLIC-KEYS { pk-ml-dsa-87 }  
  SMIME-CAPS { IDENTIFIED BY id-ml-dsa-87 }  
}
```

NOTE: The above syntax is from [RFC5912] and is compatible with the 2021 ASN.1 syntax [X680]. See [RFC5280] for the 1988 ASN.1 syntax.

The identifiers defined in Section 2 can be used as the `AlgorithmIdentifier` in the `signatureAlgorithm` field in the sequence `Certificate/CertificateList` and in the `signature` field in the sequence `TBSCertificate/TBSCertList` in certificates and CRLs, respectively, [RFC5280]. The parameters of these signature algorithms **MUST** be absent, as explained in Section 2. That is, the `AlgorithmIdentifier` **SHALL** be a SEQUENCE of one component, the OID `id-ml-dsa-*`, where `*` is 44, 65, or 87 -- see Section 2.

The `signatureValue` field contains the corresponding ML-DSA signature computed upon the ASN.1 DER-encoded `tbsCertificate/tbsCertList` [RFC5280]. The optional context string (`ctx`) parameter as defined in Section 5.2 of [FIPS204] is left to its default value: the empty string.

Conforming Certification Authority (CA) implementations **MUST** specify the algorithms explicitly by using the OIDs specified in [Section 2](#) when encoding ML-DSA signatures in certificates and CRLs. Conforming client implementations that process certificates and CRLs using ML-DSA **MUST** recognize the corresponding OIDs. Encoding rules for ML-DSA signature values are specified in [Section 2](#).

4. ML-DSA Public Keys in PKIX

In the X.509 certificate, the `subjectPublicKeyInfo` field has the `SubjectPublicKeyInfo` type, which has the following ASN.1 syntax:

```
SubjectPublicKeyInfo {PUBLIC-KEY: IOSet} ::= SEQUENCE {  
    algorithm      AlgorithmIdentifier {PUBLIC-KEY, {IOSet}},  
    subjectPublicKey BIT STRING  
}
```

NOTE: The above syntax is from [\[RFC5912\]](#) and is compatible with the 2021 ASN.1 syntax [\[X680\]](#). See [\[RFC5280\]](#) for the 1988 ASN.1 syntax.

The fields in `SubjectPublicKeyInfo` have the following meaning:

- `algorithm` is the algorithm identifier and parameters for the public key (see above).
- `subjectPublicKey` contains the public key.

Algorithm 22 in Section 7.2 of [\[FIPS204\]](#) defines the raw byte string encoding of an ML-DSA public key. When used in a `SubjectPublicKeyInfo` type, the `subjectPublicKey BIT STRING` contains this raw byte string encoding of the public key. When an ML-DSA public key appears outside of a `SubjectPublicKeyInfo` type in an environment that uses ASN.1 encoding, it could be encoded as an `OCTET STRING` by using the `ML-DSA-44-PublicKey`, `ML-DSA-65-PublicKey`, and `ML-DSA-87-PublicKey` types corresponding to the correct key size defined below.

The PUBLIC-KEY ASN.1 types for ML-DSA are defined here:

```
pk-ml-dsa-44 PUBLIC-KEY ::= {  
  IDENTIFIER id-ml-dsa-44  
  -- KEY no ASN.1 wrapping --  
  CERT-KEY-USAGE  
    { digitalSignature, nonRepudiation, keyCertSign, cRLSign }  
  PRIVATE-KEY ML-DSA-44-PrivateKey } -- defined in Section 6  
  
pk-ml-dsa-65 PUBLIC-KEY ::= {  
  IDENTIFIER id-ml-dsa-65  
  -- KEY no ASN.1 wrapping --  
  CERT-KEY-USAGE  
    { digitalSignature, nonRepudiation, keyCertSign, cRLSign }  
  PRIVATE-KEY ML-DSA-65-PrivateKey } -- defined in Section 6  
  
pk-ml-dsa-87 PUBLIC-KEY ::= {  
  IDENTIFIER id-ml-dsa-87  
  -- KEY no ASN.1 wrapping --  
  CERT-KEY-USAGE  
    { digitalSignature, nonRepudiation, keyCertSign, cRLSign }  
  PRIVATE-KEY ML-DSA-87-PrivateKey } -- defined in Section 6  
  
ML-DSA-44-PublicKey ::= OCTET STRING (SIZE (1312))  
  
ML-DSA-65-PublicKey ::= OCTET STRING (SIZE (1952))  
  
ML-DSA-87-PublicKey ::= OCTET STRING (SIZE (2592))
```

NOTE: The above syntax is from [\[RFC5912\]](#) and is compatible with the 2021 ASN.1 syntax [\[X680\]](#). See [\[RFC5280\]](#) for the 1988 ASN.1 syntax.

[\[RFC5958\]](#) specifies the Asymmetric Key Package's `OneAsymmetricKey` type for encoding asymmetric keypairs. When an ML-DSA private key or keypair is encoded as a `OneAsymmetricKey`, it follows the description in [Section 6](#).

When the ML-DSA private key appears outside of an Asymmetric Key Package in an environment that uses ASN.1 encoding, it can be encoded using one of the `ML-DSA-PrivateKey CHOICE` formats defined in [Section 6](#). The seed format is **RECOMMENDED** as it efficiently stores both the private and public key.

[Appendix C](#) contains example ML-DSA public keys encoded using the textual encoding defined in [\[RFC7468\]](#).

5. Key Usage Bits

The intended application for the key is indicated in the `keyUsage` certificate extension; see [Section 4.2.1.3](#) of [\[RFC5280\]](#). If the `keyUsage` extension is present in a certificate that includes `id-ml-dsa-*` (where `*` is 44, 65, or 87 -- see [Section 2](#)) in the `SubjectPublicKeyInfo`, then the subject public key can only be used for verifying digital signatures on certificates or CRLs, or those used in an entity authentication service, a data origin authentication service, an integrity

service, and/or a non-repudiation service that protects against the signing entity falsely denying some action. This means that the `keyUsage` extension **MUST** have at least one of the following bits set:

- `digitalSignature`
- `nonRepudiation`
- `keyCertSign`
- `cRLSign`

ML-DSA subject public keys cannot be used to establish keys or encrypt data, so the `keyUsage` extension **MUST NOT** have any of the following bits set:

- `keyEncipherment`
- `dataEncipherment`
- `keyAgreement`
- `encipherOnly`
- `decipherOnly`

Requirements about the `keyUsage` extension bits defined in [\[RFC5280\]](#) still apply.

6. Private Key Format

[\[FIPS204\]](#) specifies two formats for an ML-DSA private key: a 32-octet seed (`xi`) and an (expanded) private key. The expanded private key (and public key) is computed from the seed using `ML-DSA.KeyGen_internal(xi)` (algorithm 6).

"Asymmetric Key Packages" [\[RFC5958\]](#) specifies how to encode a private key in a structure that both identifies what algorithm the private key is for and allows for the public key and additional attributes about the key to be included as well. For illustration, the ASN.1 structure `OneAsymmetricKey` is replicated below.

```
OneAsymmetricKey ::= SEQUENCE {
    version                Version,
    privateKeyAlgorithm    SEQUENCE {
        algorithm          PUBLIC-KEY.&id({PublicKeySet}),
        parameters         PUBLIC-KEY.&Params({PublicKeySet}
                                {@privateKeyAlgorithm.algorithm})
                                OPTIONAL}
    privateKey             OCTET STRING (CONTAINING
                                PUBLIC-KEY.&PrivateKey({PublicKeySet}
                                {@privateKeyAlgorithm.algorithm})),
    attributes             [0] Attributes OPTIONAL,
    ...
    [[2: publicKey        [1] BIT STRING (CONTAINING
                                PUBLIC-KEY.&Params({PublicKeySet}
                                {@privateKeyAlgorithm.algorithm})
                                OPTIONAL ]],
    ...
}
```

NOTE: The above syntax is from [\[RFC5958\]](#) and is compatible with the 2021 ASN.1 syntax [\[X680\]](#).

For ML-DSA private keys, the `privateKey` field in `OneAsymmetricKey` contains one of the following DER-encoded CHOICE structures. The seed format is a fixed 32-byte OCTET STRING (34 bytes total with the 0x8020 tag and length) for all security levels, while the expandedKey and both formats vary in size by security level:

```
ML-DSA-44-PrivateKey ::= CHOICE {  
  seed [0] OCTET STRING (SIZE (32)),  
  expandedKey OCTET STRING (SIZE (2560)),  
  both SEQUENCE {  
    seed OCTET STRING (SIZE (32)),  
    expandedKey OCTET STRING (SIZE (2560))  
  }  
}  
  
ML-DSA-65-PrivateKey ::= CHOICE {  
  seed [0] OCTET STRING (SIZE (32)),  
  expandedKey OCTET STRING (SIZE (4032)),  
  both SEQUENCE {  
    seed OCTET STRING (SIZE (32)),  
    expandedKey OCTET STRING (SIZE (4032))  
  }  
}  
  
ML-DSA-87-PrivateKey ::= CHOICE {  
  seed [0] OCTET STRING (SIZE (32)),  
  expandedKey OCTET STRING (SIZE (4896)),  
  both SEQUENCE {  
    seed OCTET STRING (SIZE (32)),  
    expandedKey OCTET STRING (SIZE (4896))  
  }  
}
```

NOTE: The above syntax is from [\[RFC5912\]](#) and is compatible with the 2021 ASN.1 syntax [\[X680\]](#). See [\[RFC5280\]](#) for the 1988 ASN.1 syntax.

The CHOICE allows three representations of the private key:

1. The seed format (tag [0]) contains just the 32-byte seed value (xi) from which both the expanded private key and public key can be derived using `ML-DSA.KeyGen_internal(xi)`.
2. The expandedKey format contains the expanded private key that was derived from the seed.
3. The both format contains both the seed and expanded private key, allowing for interoperability; some may want to use and retain the seed and others may only support expanded private keys.

When encoding an ML-DSA private key in a `OneAsymmetricKey` object, any of these three formats may be used, though the seed format is **RECOMMENDED** for storage efficiency.

The `privateKeyAlgorithm` field uses the `AlgorithmIdentifier` structure with the appropriate OID as defined in [Section 2](#). If present, the `publicKey` field will hold the encoded public key as defined in [Section 4](#).

NOTE: While the private key can be stored in multiple formats, the seed-only format is **RECOMMENDED** as it is the most compact representation. Both the expanded private key and the public key can be deterministically derived from the seed using `ML-DSA.KeyGen_internal(xi)`. Alternatively, the public key can be generated from

the private key. While the `publicKey` field and `expandedKey` format are technically redundant when using the seed-only format, they **MAY** be included to enable keypair consistency checks during import operations.

When parsing the private key, the ASN.1 tag explicitly indicates which variant of CHOICE is present. Implementations should use the context-specific tag IMPLICIT [0] (raw value 0x80) for seed, OCTET STRING (0x04) for `expandedKey`, and SEQUENCE (0x30) for both to parse the private key, rather than any other heuristic like length of the enclosing OCTET STRING.

[Appendix C](#) contains example ML-DSA private keys encoded using the textual encoding defined in [\[RFC7468\]](#).

7. IANA Considerations

For the ASN.1 module in [Appendix A](#), IANA has assigned the following object identifier (OID) in the "SMI Security for PKIX Module Identifier" registry (1.3.6.1.5.5.7.0):

Decimal	Description	Reference
119	id-mod-x509-ml-dsa-2025	RFC 9881

Table 1

8. Operational Considerations

8.1. Private Key Format

An `ML-DSA.KeyGen seed (xi)` represents the **RECOMMENDED** format for storing and transmitting ML-DSA private keys. This format is explicitly permitted by [\[FIPS204\]](#) as an acceptable representation of a keypair. In particular, generating the seed in one cryptographic module and then importing or exporting it into another cryptographic module is allowed. The internal key generation function `ML-DSA.KeyGen_internal(xi)` can be accessed for this purpose.

Note also that unlike other private key compression methods in other algorithms, expanding a private key from a seed is a one-way function, meaning that once a full key is expanded from seed and the seed discarded, the seed cannot be recreated, even if the full expanded private key is available. For this reason, it is **RECOMMENDED** that implementations retain and export the seed, even when also exporting the expanded private key. ML-DSA seed extraction can be implemented by including the seed `xi` that is randomly generated at line 1 of Algorithm 1 `ML-DSA.KeyGen` in the returned output.

When encoding an ML-DSA private key in a `OneAsymmetricKey` object, any of these three formats may be used, though the seed format is **RECOMMENDED** for storage efficiency.

8.2. Private Key Consistency Testing

When receiving a private key that contains both the seed and the expandedKey, the recipient **SHOULD** perform a seed consistency check to ensure that the sender properly generated the private key. Recipients that do not perform this seed consistency check avoid keygen and compare operations, but are unable to ensure that the seed and expandedKey match.

If the check is done and the seed and the expandedKey are not consistent, the recipient **MUST** reject the private key as malformed.

The seed consistency check consists of regenerating the expanded form from the seed via `ML-DSA.KeyGen_internal`, and ensuring it is bitwise equal to the value presented in the private key.

[Appendix C.4](#) includes some examples of inconsistent seeds and expanded private keys.

8.3. Rationale for Disallowing HashML-DSA

The HashML-DSA mode defined in Section 5.4 of [\[FIPS204\]](#) **MUST NOT** be used; in other words, public keys identified by `id-hash-ml-dsa-44-with-sha512`, `id-hash-ml-dsa-65-with-sha512`, and `id-hash-ml-dsa-87-with-sha512` **MUST NOT** be in X.509 certificates used for CRLs, OCSP, certificate issuance, and related PKIX protocols. This restriction is primarily to increase interoperability.

ML-DSA and HashML-DSA are incompatible algorithms that require different `Verify()` routines. This introduces the complexity of informing the verifier whether to use `ML-DSA.Verify()` or `HashML-DSA.Verify()`. Additionally, since the same OIDs are used to identify the ML-DSA public keys and ML-DSA signature algorithms, an implementation would need to commit a given public key to be either of type ML-DSA or HashML-DSA at the time of certificate creation. This is anticipated to cause operational issues in contexts where the operator does not know whether the key will need to produce pure or pre-hashed signatures at key-generation time. The External μ (mu) mode described in [Appendix D](#) avoids all of these operational concerns.

A minor security reason for disallowing HashML-DSA is that the design of the ML-DSA algorithm provides enhanced resistance against collision attacks, compared with HashML-DSA or conventional RSA or ECDSA signature algorithms. Specifically, ML-DSA prepends the SHAKE256 hash of the public key (`tr`) to the message to-be-signed prior to hashing, as described in line 6 of Algorithm 7 of [\[FIPS204\]](#). This means that in the unlikely discovery of a collision attack against the SHA-3 family, an attacker would have to perform a public-key-specific collision search in order to find message pairs such that $H(tr || m1) = H(tr || m2)$, because a direct hash collision $H(m1) = H(m2)$ will not suffice. HashML-DSA removes this enhanced security property. In spite of its lack of targeted collision protection, the practical security risk of using HashML-DSA in X.509 signatures would be immaterial. This is because a hash of the issuing CA's public key is already included in the Authority Key Identifier (AKI) extension, which is signed as part of the `tbsCertificate` structure. Even when it is a SHA-1 hash, general second pre-images against the AKI hash of existing issuing CAs would be impractical.

9. Security Considerations

The Security Considerations section of [\[RFC5280\]](#) applies to this specification as well.

The ML-DSA signature scheme is strongly unforgeable under chosen message attacks (SUF-CMA). For the purpose of estimating security strength, it has been assumed that the attacker has access to signatures for no more than 2^{64} chosen messages.

ML-DSA depends on high quality random numbers that are suitable for use in cryptography. The use of inadequate pseudo-random number generators (PRNGs) to generate such values can significantly undermine various security properties. For instance, using an inadequate PRNG for key generation, might allow an attacker to efficiently recover the private key by trying a small set of possibilities, rather than brute-force search the whole keyspace. The generation of random numbers of a sufficient level of quality for use in cryptography is difficult; see Section 3.6.1 of [\[FIPS204\]](#) for some additional information.

In the design of ML-DSA, care has been taken to make side-channel resilience easier to achieve. For instance, ML-DSA does not depend on Gaussian sampling. Implementations must still take great care not to leak information via various side channels. While deliberate design decisions such as these can help to deliver a greater ease of secure implementation -- particularly against side-channel attacks -- it does not necessarily provide resistance to more powerful attacks such as differential power analysis. Some amount of side-channel leakage has been demonstrated in parts of the signing algorithm (specifically the bit-unpacking function), from which a demonstration of key recovery has been made over a large sample of signatures. Masking countermeasures exist for ML-DSA, but comes with performance overhead.

ML-DSA offers both deterministic and randomized signing. Signatures generated with either mode are compatible and a verifier can't tell them apart. In the deterministic case, a signature only depends on the private key and the message to be signed. This makes the implementation easier to test and does not require a randomness source during signing. In the randomized case, signing mixes in a 256-bit random string from an approved random bit generator (RBG). When randomized, ML-DSA is easier to harden against fault and hardware side-channel attacks.

A security property that is also associated with digital signatures is non-repudiation. Non-repudiation refers to the assurance that the owner of a signature key pair that was capable of generating an existing signature corresponding to certain data cannot convincingly deny having signed the data, unless its private key was compromised. The digital signature scheme ML-DSA possesses three security properties beyond unforgeability, that are associated with non-repudiation. These are exclusive ownership, message-bound signatures, and non-resignability. These properties are based tightly on the assumed collision resistance of the hash function used (in this case SHAKE-256). A full discussion of these properties in ML-DSA can be found at [\[CDFJ21\]](#).

10. References

10.1. Normative References

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Appendix A. ASN.1 Module

This appendix includes the ASN.1 module [X680] for the ML-DSA. Note that as per [RFC5280], certificates use the Distinguished Encoding Rules; see [X690]. This module imports objects from [RFC5912].

```
<CODE BEGINS>
X509-ML-DSA-2025
{ iso(1) identified-organization(3) dod(6)
  internet(1) security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-x509-ml-dsa-2025(119) }

DEFINITIONS IMPLICIT TAGS ::= BEGIN

EXPORTS ALL;

IMPORTS

PUBLIC-KEY, SIGNATURE-ALGORITHM
FROM AlgorithmInformation-2009 -- [RFC 5912]
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-algorithmInformation-02(58) } ;

--
```

```
-- ML-DSA Identifiers
--

nistAlgorithms OBJECT IDENTIFIER ::= { joint-iso-itu-t(2)
    country(16) us(840) organization(1) gov(101) csor(3)
    nistAlgorithms(4) }

sigAlgs OBJECT IDENTIFIER ::= { nistAlgorithms 3 }

id-ml-dsa-44 OBJECT IDENTIFIER ::= { sigAlgs 17 }
id-ml-dsa-65 OBJECT IDENTIFIER ::= { sigAlgs 18 }
id-ml-dsa-87 OBJECT IDENTIFIER ::= { sigAlgs 19 }

--
-- Public Key Algorithms
--

PublicKeys PUBLIC-KEY ::= {
    -- This expands PublicKeys from [RFC 5912]
    pk-ml-dsa-44 |
    pk-ml-dsa-65 |
    pk-ml-dsa-87,
    ...
}

--
-- ML-DSA Public Keys
--

pk-ml-dsa-44 PUBLIC-KEY ::= {
    IDENTIFIER id-ml-dsa-44
    -- KEY no ASN.1 wrapping; 1312 octets --
    PARAMS ARE absent
    CERT-KEY-USAGE { digitalSignature, nonRepudiation,
                     keyCertSign, cRLSign }
    PRIVATE-KEY ML-DSA-44-PrivateKey
}

ML-DSA-44-PrivateKey ::= CHOICE {
    seed [0] OCTET STRING (SIZE (32)),
    expandedKey OCTET STRING (SIZE (2560)),
    both SEQUENCE {
        seed OCTET STRING (SIZE (32)),
        expandedKey OCTET STRING (SIZE (2560))
    }
}

pk-ml-dsa-65 PUBLIC-KEY ::= {
    IDENTIFIER id-ml-dsa-65
    -- KEY no ASN.1 wrapping; 1952 octets --
    PARAMS ARE absent
    CERT-KEY-USAGE { digitalSignature, nonRepudiation,
                     keyCertSign, cRLSign }
    PRIVATE-KEY ML-DSA-65-PrivateKey
}
```

```
ML-DSA-65-PrivateKey ::= CHOICE {
  seed [0] OCTET STRING (SIZE (32)),
  expandedKey OCTET STRING (SIZE (4032)),
  both SEQUENCE {
    seed OCTET STRING (SIZE (32)),
    expandedKey OCTET STRING (SIZE (4032))
  }
}

pk-ml-dsa-87 PUBLIC-KEY ::= {
  IDENTIFIER id-ml-dsa-87
  -- KEY no ASN.1 wrapping; 2592 octets --
  PARAMS ARE absent
  CERT-KEY-USAGE { digitalSignature, nonRepudiation,
                    keyCertSign, cRLSign }
  PRIVATE-KEY ML-DSA-87-PrivateKey
}

ML-DSA-87-PrivateKey ::= CHOICE {
  seed [0] OCTET STRING (SIZE (32)),
  expandedKey OCTET STRING (SIZE (4896)),
  both SEQUENCE {
    seed OCTET STRING (SIZE (32)),
    expandedKey OCTET STRING (SIZE (4896))
  }
}

ML-DSA-44-PublicKey ::= OCTET STRING (SIZE (1312))
ML-DSA-65-PublicKey ::= OCTET STRING (SIZE (1952))
ML-DSA-87-PublicKey ::= OCTET STRING (SIZE (2602))

--
-- Signature Algorithms
--

SignatureAlgorithms SIGNATURE-ALGORITHM ::= {
  -- This expands SignatureAlgorithms from [RFC 5912]
  sa-ml-dsa-44 |
  sa-ml-dsa-65 |
  sa-ml-dsa-87,
  ... }

--
-- ML-DSA Signature Algorithm Identifiers
--

sa-ml-dsa-44 SIGNATURE-ALGORITHM ::= {
  IDENTIFIER id-ml-dsa-44
  PARAMS ARE absent
  PUBLIC-KEYS { pk-ml-dsa-44 }
  SMIME-CAPS { IDENTIFIED BY id-ml-dsa-44 }
}

sa-ml-dsa-65 SIGNATURE-ALGORITHM ::= {
  IDENTIFIER id-ml-dsa-65
  PARAMS ARE absent
}
```

```

PUBLIC-KEYS { pk-ml-dsa-65 }
SMIME-CAPS { IDENTIFIED BY id-ml-dsa-65 }
}

sa-ml-dsa-87 SIGNATURE-ALGORITHM ::= {
  IDENTIFIER id-ml-dsa-87
  PARAMS ARE absent
  PUBLIC-KEYS { pk-ml-dsa-87 }
  SMIME-CAPS { IDENTIFIED BY id-ml-dsa-87 }
}

END

<CODE ENDS>

```

Appendix B. Security Strengths

Instead of defining the strength of a quantum algorithm in a traditional manner using the imprecise notion of bits of security, NIST has instead elected to define security levels by picking a reference scheme, which NIST expects to offer notable levels of resistance to both quantum and classical attacks. To wit, an algorithm that achieves NIST PQC security level 1 must require computational resources to break the relevant security property, which are greater than those required for a brute-force key search on AES-128. Levels 3 and 5 use AES-192 and AES-256 as references, respectively. Levels 2 and 4 use collision search for SHA-256 and SHA-384 as references.

The parameter sets defined for NIST security levels 2, 3, and 5 are listed in Figure 1, along with the resulting signature size, public key, and private key sizes in bytes. Note that these are the sizes of the raw keys, not including ASN.1 encoding overhead from `OneAsymmetricKey` and `SubjectPublicKeyInfo` wrappers. Private key sizes are shown for both the seed format and expanded format.

Level	(k,l)	eta	Sig. (B)	Public Key(B)	Private Seed(B)	Private Expand(B)
2	(4,4)	2	2420	1312	32	2560
3	(6,5)	4	3309	1952	32	4032
5	(8,7)	2	4627	2592	32	4896

Table 2: ML-DSA Parameters

Appendix C. Examples

This appendix contains examples of ML-DSA private keys, public keys, certificates, and inconsistent seed and expanded private keys.

C.1. Example Private Keys

The following examples show ML-DSA private keys in different formats, all derived from the same seed `000102...1e1f`. For each security level, we show the seed-only format (using a context-specific `[0]` primitive tag with an implicit encoding of `OCTET STRING`), the expanded format, and both formats together.

NOTE: All examples use the same seed value, showing how the same seed produces different expanded private keys for each security level.

C.1.1. ML-DSA-44 Private Key Examples

Each of the examples includes the textual encoding [RFC7468] followed by the so-called "pretty print"; the private keys are the same.

C.1.1.1. Seed Format

```
-----BEGIN PRIVATE KEY-----
MDQCAQAwCwYJYIZIAWUDBAMRBCAIAABAgMEBQYHCAkKCwwNDg8QERITFBUWFxgZ
GhscHR4f
-----END PRIVATE KEY-----
```

```
SEQUENCE {
  INTEGER { 0 }
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
  }
  OCTET_STRING {
    [0 PRIMITIVE] { `000102030405060708090a0b0c0d0e0f10111213141
5161718191a1b1c1d1e1f` }
  }
}
```

C.1.1.2. Expanded Format

-----BEGIN PRIVATE KEY-----

MIIKGAIBADALBg1ghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0s19jx0X
0Xidr6FwJLMW6b7J0c4Pf3f421ZE3No2a/5HNL2V9DX/mmE6pUqkHCxpTAQymgex
+rtI9SownxGhiY+EjiMi/+Yj7IENs77jNoWFSogmnaMg1RIL/P6JoY4w9xFNg6pA
SmRrbJlziYYNElIu4ABuI4SBkYZhmyYNEYZk1KYoiHhEgkAomBRhSKZhTEJIoZII
wjgpUSRICKElwggxCMRxIBQJFINsGKeAhBBuyCBwIrVkcLBhDAcEmBJEUYhpWQBG
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TbL08CFkqhREqFk
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYsUmGJMMWEGpZtSpqsmQZtpEQyIKdkWjJu
EbVwIJJhJB00BIUsCkhyyKBR0wgqmsCAWCQgJAd0WRSIEKrkYMBt4LKNgXkJIDQi
wCRBUNCxCIeGYaIBUiJSG4CAmJQAE5NN0zIpIhcKmJJPgHRRICchnMagYqKBSBhp
GoVNg0RpWyBBAXJCyxhGAakNDAXg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy
UjJyVKZAWHgQDDISksKAUhJiXIIoC7RsA0KNUxAMFAE04TZSiIQkkQIKY0YmIAYp
EcIo0CBIArNsojYJWoZiY7Rhi0ZixECCGokJEAJNJLJFIBILJMKFiCiMycBNWUgi
CiduwTRkTJBgW0RQgoZJQ4gEQ7KMYDCAoogthKRtjKYp0MaEQgZGiYhRAkMNAUmN
5DgNpAaN05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdLJChIFciQCRBh2UAiGzNg
CQKS0CSBIAQISRheoyItXIhEFJgIpEZhAZVkcZkKDJRQykbQ0rIgwDgBgjCOE7kI
kYCEFipwBiRejUNoCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp
GiKJFEUR3IJEUJZFDESEwLIEmqYFQ4YsRDJuiEQhIKhMmjBw47gtYyaIAyVJA00M
SKgJyhRyUzR0EkMIG6cEWTAi2ZSA4jQigUISnDAqLDQmYQRFJCYoE0YJSjJtESgJ
GLglYigRE0ENQbIRKIRMIxISosaIycAwIgyG0hi0hIYwKERSEogx2SBxE8UoQwY0
AzBgZKaEWCZSTIGBHvclYshf+k0s+kkhfysXLXu8FGIObZgKcaq73wxF6aIG7LFC
P+4V3swXYBMAFJ2SI81ubG4fQ0Qfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrhMhVI8
qP5srSlK340+FbEI/3IdDMh7w906dZAYS6EVm0pH8nhw8U6YdhnQgsE8JI1V108
ZaBjaP1BKV/QmSQLG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWM1795EeB6ptCTjy
7iuzwajFldY16ENC/eoB3CSyEa0vwoHPd+WREMerxUvwyG1IC5vidkcdydYDzumM
/as+n8+3A3k1YfSepEUpp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFeyzNp0Y+
SSKM0j2KHzeFbxQt7kNsJ+Cr4kljG0quAR6gMA2yTV+ogRvjcyY1TwxSlfNCu0F9
PP6wsf0zYiwp4Uy72S4TY8ZevUUEt1EjKblnDjLhssZ6V0fxpV+Ln56gToyjpwXm
KjxeY3N0r7eutt3qYSzeKPAaIC16pONHITJ90/m4mJTQGF1dTXEZ7+Ny07oQTLi7
CYHgdN46/iANqq6tgmzEXyRNv0Ma+rNO+994JHTS/VcRj2RiFJNO2Zy60wA+jWej
g29vGfxBkQzlfj7jrpnrhNUU63YeY2h0pW+XkdLdSxuxYWi5SMgX91oiKss0jNwD
zEr+j2cVfho203+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTewZz3N0/xfNLhV3MbH
eIVknp5x9D1K6g9Lcsp+2gV4uhPTGmWNLQYKmmB/ae0b5516L7HScj04+b+r4Y+0
ezzakG50m16ULI6uspYHDr/TZJR61AzJeL7Wazd0nm1dzXvoxJREDiuEzs/vuYwL
7fs8QeM1nSzXGX++cgxIqmXrZGXB7mPjVpwq3HREkTcLf3gm/gt3odGdZBAduYR
gQa0LS73N0f1YB/kuLDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD
AZxvXCfLmNomFEtkIlp8kysw92Hnii1Zodi4PsY0Si9t1H52VwbQC/SnmqSbDup
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U51h1kKjM+n1k9bj9TU51CCOnmozKF
HX91JSKpKLkX4n4tbUITff4uv6b7HGeybAJUOaF9+vb4xWmjgotp2noqfQtPmA
fHEZCSaywAetg+rU5P0e2HLM0ZciAdKwJ/NUwSLTDNeLwddA/sy8b8KgRGxuM0rF
H1ppCYqi1EfyCFt0TkuSZmJpIdLeR4UYzQkM4meuotJ621f9iLSXbYn7hDzc0mn
bKJnnmgBv6f7AxIW+1BilwS5kj2u13ThTERICrfsRmV5ZtZA0z2ftA6uBOGdkjQ
JYKAh+1Jqa/Ra5XXLZmx7coleqTL/t6Bwmu1anA/wX7Dyu/KECe7XtfWAG+1kzt
AZ4ct4Ud0FHxApBnThn/sAizAcSs9KgiuxQhbb1pyr9Ste8idJaw8weZqFXRF/rT
dEpvozUD6nmLUt3X71QmYJ2/zT8ME7Fk1sBR9+1KEZcZpxLjinMoQCCB/xNUTVTS
wjev7TsVHEuo6fS964SZowZuJrvGnorwid7HFzHR3Fkeqxfvc3RzTA/kdU1Mg4Nr
3TSg05vImRRxYGG/uY7G5hw+1E003K81JDxkcIa56nAYsNmoolAM7LAKveJJjWnC
M2EBp3LL5PVxUj9RvQWILN81i4ScwUCqH68iQjoShRzg4z/UiXWk1Z+1xf5BjJ0Q
gZGrbnQbd7/gLL1pjueVxGbWFWGeZEE4LG6sAYN06atzzqgLviNceNqRvXm2+C+J
l4XWhwDTk+Z1wiJNa3oa0hMgSVZ5ra7XAWe1CGZx01MQnbe299gTB0zf2Dsxxm7y
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKhqhjeGHKokyh4uax+GsW9pJl7cgZP
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxnHAPC5FzuZBPs
vnUn6HPkVcTmEKYY0arMC9VtJIPnjymLZqR46y9VjLr8qGvoR7rrAsWyFsJNiP6k
3ySbCeZwogcDq6wksKkavEpWRmAUQroQvs/TCZOIAFHQf1agWpN556jmvv7j8i+q
EGOY93BgBuQum+HvidJcJy8RqVCVxYfXE3MihN6dvTxyF7BonihY6w/2lmg=

-----END PRIVATE KEY-----

```
SEQUENCE {
  INTEGER { 0 }
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
  }
  OCTET_STRING {
    OCTET_STRING { `d7b2b47254aae0db45e7930d4a98d2c97d8f1397d178
9dafa17024b316e9bec939ce0f7f77f8db5644dcda366bfe4734bd95f435ff9a
613aa54aa41c2c694c04329a07b1fabbb48f52a309f11a1898f848e2322ffe623
ec810db3bee33685854a88269da320d5120bfcfe89a18e30f7114d83aa404a64
6b6c997389860d12522ee0006e2384819186619b260d118664d4a62822184482
402898146148a6614c4248a19208c2382951244808a125c2083108c471201409
14836c18a78084106ec9c07022b56408b0610c07049812445188695900462293
2041062e42b64c01164914284c41a85180460a5116515a0820022244dc9849d1
3251e13065d3c08592a85112a1640039220946621cc70cd9086dd00626524085
80443091062c50c80924c5841a966d4a982c99066da4443220a7645a326e11b5
7020926124138e04852c0a4872c8a051d3082a99208058242024074e59148810
a46460c06de0b28d1b1909203422c024410943710a212061a2015222521b8080
9a340013934dd3322922170a9892691a14512027219cc02062a2814818691a85
4d8344695b2041031242cb184601a90d0c023183b0215a224ac89205d9906904
306a4b064ad2b2011c404081423252327254a6405a18100c321292c280521262
5c82280bb46c03428d53100c14010ee1365288842491020a63462620062911c2
28d0204802b36ca236095a8648cbb4618b4662c440821a890910024d24b24520
122524c90588288cc9c04d5948220a276ec134644c90605b4450828649438804
43b28c603080a2882d84a46d8ca629d0c68442064689885100a98d01498de438
0da4068dd3947142b26c1a84611ba32842b42808a0711ac531e0a04c01376524
2862142890091061d940221b3360090292d02481200408491844a3222d5c8844
149808a446610195640b390a0c9450ca406ad2b220c0380182308e13b9089180
84148829c0189112350da02422e20406d9c2850428121cc989180272d24029c2
0812d8062a9994719bb8682384291a2289144511dc82445096450c4484c0b204
9aa60543862c44326e88442120a84c9a3070e3b82d63268803254903438c48a8
09ca14725344e1243081ba704593022d99480e234228142129c302a94342661
04452426281346094a326d11280918b82562281113410d41b21190844c8b1212
a2c688c9c030220606d2188e848630904452128831d9207113c52843060e0330
60cca6845826524c88011ef72562c85ffa43acfa49217f2b172d7bbc14620e6d
980a71aabbbdf0c45e9a206ecb1423fee15decc17601300149d9223cd6e6c6e1f
a8e41fc7c64938ab68905fd3dcda50d87082e7d0d71d1bc9b2b84c85523ca8fe
6cad294adf83be15b108ff721d0cc87bc3dd3a7590184b0e845663a91fc9e1c3
c53a61d867420b04f092355753bc65a06368fd41295fd09924132c6f91f67964
c142674a725c343914c4cecf58c074bcfa4558c97bf7911e07aa6d0938f2ee2b
b3c1a8c595d635e84342fdea01dc24b211ad2fc281cf77e59110c7abc54bf0c8
6d480b9be276471dc9d603cee98cfadab3e9fcfb703793560549ea4450fa7b33f
b9169c44b4d25fb9c457f49791cd3da03eac96095813c105132ccda4e63e4922
8cd23d8a1f37856f142d93b90db09f82af89258c63aab8047a80c036c9357ea2
046f8dc6354f0c5295f342bb417d3cfefb0b1fd33622c29e14cbbd92e1363c65e
bd4504b7512329b9670e32e1b2c67a54e7f1a55f8b9f9ea04e8ca3a705e62a3c
5e637374afb7aeb6dde612cde28f01a202d7aa4e34722d27dd3f9b89894d019
fd5d4d7119efe3723bba104cb8bb0981e074de3afe200daaaead826cc45f244d
bf431afab34efbdf782474d2fd57118f646214934ed99cba3b003e8d67a3836f
6f19fc41910ce5163ee3ae99eb84d514eb761e63684ea56f9791d2dd4aac6e61
68b948c817f75a222acb0e8cdc03cc4afe8f67157e1a363b7faeff9f172b9891
3677c5a1dd085e9ee4c22052c1af58193116673dcd3bfc5f34b855dcc6c77885
649e9e71f43d4aea0f4b72ca7eda0578ba13d31a658d2d060a9a66ff69ed1be7
997a2fb1d2723d38f9bfabe18f8e7b3cda906e4e9b5e942c8eae296070ebfd3
64947a940cc978bed66b37749e6d5dcd7be8c494440e2b84cecfefb98c0bedfb
3c41e3359d2cd7197fbe720c48aa6c6b6465c1ee63e3569c2adc744491370bf7f
7826fe0b77a1d19d64101d032b918106b42d2ef73747e5601fe4ba50f23ede52
```

```
1f031a817d15294a43722e8378784b6db0cf1ba9e8ae911d9201b9ce9cc3019c
6f5c27cb98da26144b64225a7c932b30f761e78a2d59a1d8b83ec6344a2f6dd4
7e765706d00bf4a79a6a926c3ba91d812c8f2c797ab1796709e5d16856778293
529f0286d015c3b5399619642a333e9e593d6e3f5353994208e9e6a332851d7f
652522a928b917e27e2d6d42137dfe2ebfa6fb1c67b26c0254528685f7ebdbe3
15a68eaa2da769e8a9f42d3e60007c71330926b2c0012d83ead4e4fd1ed872cc
d1972201d2b027f3545ac2d30cd78bc1d740fecbc6fc2a0446c6e30eac51f5a
69098aa2d447f2085b4e4e4b92ccc26921d2de478518cd090ce267aea2d27ada
57fd88b4976d89fb843cdccf49a76ca2679e6801bfa7fb031896fb50629704b9
923936bb5dd385311121cadfb11995e59b73034cf67ed03ab813867648d02582
8087e949a9afd16b95d72d99b1edca257aac132fffb7a0709aed5a9c0ff05fb0f
2bbf28409eed7b5f5801be964ced019e1cb7851d3851f10290674e19ffb008b3
01c4acf641a2bb14216e1d69cabf52b5ef227496b0f30799a855d117fad3744a
6fa33503ea798b52ddd7ee5426609dbfcd3f0c13b164d6c051f7ed4a119719a7
12e388d328402081ff1354b554d2c237afed3b151c4ba8e9f4bdeb8499a3066e
26bbc69e8af089dec71731d1dc529eab17ef7374734c0fe475494c83836bdd34
a03b9bc89914716061bfb98ec6e61c3ed4438edcaf25243c647086b9ea7018b0
d9a8a0b00cecb00abde2498d69c2336101a772cbe4f571523f51bd05882cdf35
8b849cc140aa1faf22423a12851ce0e33fd48975a4959fa5c5fe418c93908191
ab6e741b77bfe02cbd698ee795c466d615619e6441382c6eac01834ee9ab73ce
a80bbe235c78da91bd79b6f82f899785d68700d393e675c2224d6b7a1ad21320
495679adaed70167b50866713a53109db7b6f7d81304ecdfd83b319b1ef24830
6b45ad29e7ddcc863dac56048b5d69ea175011f7614c00a86a863cde1872a893
2878b9ac7e1ac5bda4997b72064f0cd75f4c814e034de11acb9013cf7ea926b4
e7eaace070c7ba2188efad2e431e1223d45dd05c4d8403c2e45cee6413ecbe75
27e873e455c4e610a61839aacc0bd56d2483e78f298b66a478eb2f558cbafca8
6be847baeb02c5b216c8cd88fea4df249b09e670a20703abac24b0a91abc4a56
46601442ba10becfd30993880051d07f56a05a9379e7a8e6befee3f22faa1063
98f7706006e42e9be1ef89d25c272f11a95095c587d713732284de9dbd3c7217
b0689e21d8eb0ff69668` }
}
}
```

C.1.1.3. Both Format

-----BEGIN PRIVATE KEY-----

MIIPKpIBADALBg1ghkgBZQMEAxEEggoqMIIKJgQgAAECAwQFBgcICQoLDA00DxAR
EhMUFYRXGBkaGxwdHh8EggoA17K0clSq4NtF55MNSpjSyX2PE5fReJ2voXAKsxbp
vsk5zg9/d/jbVKTc2jZr/kc0vZX0Nf+aYTq1SqQcLG1MBDKaB7H6u0j1KjCfEaGJ
j4S0IyL/5iPsgQ2zvuM2hYVKiCadoyDVEgv8/omhjjD3EU2DqkBKZGtsmX0Jhg0S
Ui7gAG4jhIGRhmgBjg0RhmtUpigiGESQCiYFGFIpmFMQkihkgjCOC1RJEgIoSXC
CDEIxHEgFakUg2wYp4CEEg7JwHAitWQIsGEMBwSYEkRRiG1ZAEYikyBBBi5CtkwB
FkkUKExBqFGARgpRf1FaCCACIkTcmEnRM1HhMGXTwIWSqFESoWQAOSIJRmIcxwzZ
CG3QBiZSQIWARDCRBixQyAkKxYQa1m1KmCyZBm2kRDIgp2RaMm4RtXAgkmEkE44E
hSwKSHLIoFHTCCqZIIByJCAkBO5ZFgQpGRgwG3gso0bGQkgNCLAJEEJQ3EKISBh
ogFSiIibgICaNAATk03TMikiFwqYkmaFFeGjYgCwCBiooFIGGkahU2DRG1bIEED
EkLLGEYBqQ0MAjGDsCFaIkRikgXZkGkEMGpLBkrSsgEcQECBQjJSMnJUpkBaGBAM
MhKSwoBSEmJcgigLtGwDQo1TEAwUAQ7hN1K1hCSRAGpjRiYgBikRwjiQIEgCs2yi
NglahkjLtGGLRmLEQIIaiQkQAK0kskUgEiUkyQWIKIzJwE1ZSCIKJ27BNGRMGbBb
RFCCChk1DiARDsoxgMICiic2EpG2MpinQxoRCBkaJiFEaqY0BSY3k0A2kBo3T1HFC
smwahGEboyhCtCgIoHEaxTHgoEwBN2UkKGIUKJAJEHGHZQCIbM2AJApLQJIEgBAhJ
GESjIi1ciEQUmAikRmEBLWQLOQoM1FDKQGrSsiDA0AGCMI4TuQiRgIQUiCnAGJES
NQ2gJCLiBAbZwoUEKBiCyYkYAnLSQCnCCBLyBiQZLHGbuGgjhCkaIokURRHcgkRQ
lkUMRITASgSapgVDhixEMm6IRCEggYeaMHDjuC1jJogDJUkDQ4xIqAnKFHJTNE4S
QwgbpWRZMCLZ1IDiNCKBQhKcMCqUNCZhBEUKjigTRglKMm0RKAKYucViKBETQ01B
shGQhEylEhKixojJwDAiBgbSGI6EhjCQRFISiDHZIHETxShDBg4DMGDMpoRYJ1JM
iAEe9yViyF/6Q6z6SSF/Kxcte7wUYg5tmApqrvfDEXpogbssUI/7hXezBdgEwAU
nZiJzW5sbh+o5B/Hxkk4q2iQX9Pc2LDYcILn0NcdG8myuEyFUjyo/mytKUrfg74V
sQj/ch0MyHvD3Tp1kBhLDoRWY6kfyeHDXtPh2GdCCwTwkjVXU7x1oGNo/UEpX9CZ
JBMSb5H2eWTBQmdKclw0ORTEzs9YwHS8r0VYyXv3kR4Hqm0JOPLuK7PBqMWV1jXo
Q0L96gHcJLIRs/Cgc935ZEQx6vFS/DiBtUgLm+J2Rx3J1gP06Yz9qz6fz7cDeTVg
VJ6kRQ+nsz+5FpxEtNjFucRX9JeRzT2gPqyWCVgTwQUTLM2k5j5JIoZSPYofN4Vv
FC2TuQ2wn4KviSWMY6q4BHqAwDbJNX6iBG+NxjVPDFKV80K7QX08/rCx/TNiLCnh
TLvZLhNjx169RQ3USMpuWc0MuGyxnpU5/G1X4ufnqB0jK0nBeYqPF5jc3Svt662
3ephLN408BogLXqk40ci0n3T+biY1NAZ/V1NcRnv43I7uhBMuLsJgeB03jr+IA2q
rq2CbMRfJE2/Qxr6s07733gkdNL9VxGPZGIUK07ZnLo7AD6NZ60Db28Z/EGRD0UW
Pu0umeuE1RTrdh5jaE61b5eR0t1KrG5haL1IyBf3WiIqyw6M3APMSv6PZxV+GjY7
f67/nxcrmJE2d8Wh3QhenuTCIFLBr1gZMRZnPc07/F80uFXcxs4hWSEnnH0PURq
D0tyyn7aBXi6E9MaZY0tBgqaZv9p7RvnmXovsdJyPTj5v6vhj457PNqQbk6bXpQs
jq6y1gc0v9Nk1HqUDM14vtZrN3SebV3Ne+jE1EQ0K4T0z++5jAvt+zxB4zWdLncZ
f75yDEiqbGtKzChuY+NWnCrCdESRnwt/eCb+C3eh0Z1KEB0DK5GBBRQtLvc3R+Vg
H+S6UPI+3lIfAxqBfRUpSkNyLoN4eEttsM8bqeiukR2SAbn0nMMBnG9cJ8uY2iYU
S2QiWnyTKzD3YeeKLVmh2Lg+xjRKL23UfnZXBtAL9KaaPJs06kdGsyPLH16sXln
CeXRaFZ3gpNSnwKG0BXDtTmWGWWQmZ6eWT1uP1NTmUII6eajMoUdf2U1IqkouRfi
fi1tQhN9/i6/pvscZ7JsAlRShoX369vjFaa0qi2naeip9C0+YAB8cTMJJrLAAS2D
6tTk/R7YcszRlyIB0rAn81RawtMM14vB10D+zLxvwqBEbG4w6sUfWmkJiqLUR/II
W050S5LMwmkh0t5HhRjNCQziZ66i0nraV/2ItJdtifuEPNzPSadsomeeaAG/p/sD
GJb7UGKXBLmS0Ta7Xd0FMREhyt+xGZX1m3MDTPZ+0Dq4E4Z2SNA1goCH6Umpr9Fr
ldctmbHtyiV6rBMv+3oHCa7VqcD/BfsPK78oQJ7te19YAb6WT00Bnhy3hR04UfEC
kGd0Gf+wCLMBxKz2QaK7FCFuHwNkv1K17yJ01rDzB5moVdEX+tN0Sm+jNQPqeYtS
3dfuVCZgnb/NPwwTsWTWwFH37UoRlXmnEu0I0yhAIIH/E1S1VNLcN6/t0xUcS6jp
9L3rhJmjBm4mu8aeivCJ3scXMDhCUp6rF+9zdHNMD+R1SUyDg2vdNKA7m8iZFHfG
Yb+5jsbmHD7UQ47cryUkPGRwhrnqcBiw2aigsAzssAq94kmNacIzYQGncsvk9XFS
P1G9BYgs3zWLhJzBQKofryJC0hKFHODjP9SJdaSVn6XF/kGMk5CBkatudBt3v+As
vWm055XEZtYVYZ5kQTgsbqwBg07pq3P0qAu+I1x42pG9ebb4L4mXhdaHAN0T5nXC
Ik1rehrSEyBJVnmtrtcBZ7UIZnE6UxCdt7b32BME7N/Y0zGbHvJIMGtFrSnn3cyG
PaxWBItdaeoXUBH3YUwAqGqGPN4YcqiTKHi5rH4axb2kmXtyBk8M119MgU4DTEa
y5ATz36pJrTn6qzgcMe6IYjvrS5DHHij1F3QXE2EA8LkX05kE+y+dSfoc+RVx0YQ
phg5qswL1W0kg+ePKYtmpHjrL1WMuvyoa+hHuusCxbIWym2I/qTfJJJs5nCiBw0r
rCSwqRq8S1ZGYBRCuhC+z9MJk4gAuDB/VqBak3nnq0a+/uPyL6oQY5j3cGAG5C6b
4e+J01wnLxGpUJXFh9cTcyKE3p29PHIXsGieIdjrd/aWaA==

-----END PRIVATE KEY-----

```
SEQUENCE {  
  INTEGER { 0 }  
  SEQUENCE {  
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }  
  }  
  OCTET_STRING {  
    SEQUENCE {  
      OCTET_STRING { `000102030405060708090a0b0c0d0e0f1011121314  
15161718191a1b1c1d1e1f` }  
      OCTET_STRING { `d7b2b47254aae0db45e7930d4a98d2c97d8f1397d1  
789dafa17024b316e9bec939ce0f7f77f8db5644dcda366bfe4734bd95f435ff  
9a613aa54aa41c2c694c04329a07b1fabb48f52a309f11a1898f848e2322ffe6  
23ec810db3bee33685854a88269da320d5120bfcfe89a18e30f7114d83aa404a  
646b6c997389860d12522ee0006e2384819186619b260d118664d4a628221844  
82402898146148a6614c4248a19208c2382951244808a125c2083108c4712014  
0914836c18a78084106ec9c07022b56408b0610c070498124451886959004622  
932041062e42b64c01164914284c41a85180460a5116515a0820022244dc9849  
d13251e13065d3c08592a85112a1640039220946621cc70cd9086dd006265240  
8580443091062c50c80924c5841a966d4a982c99066da4443220a7645a326e11  
b57020926124138e04852c0a4872c8a051d3082a99208058242024074e591488  
10a46460c06de0b28d1b1909203422c024410943710a212061a2015222521b80  
809a340013934dd3322922170a9892691a14512027219cc02062a2814818691a  
854d8344695b2041031242cb184601a90d0c023183b0215a224ac89205d99069  
04306a4b064ad2b2011c404081423252327254a6405a18100c321292c2805212  
625c82280bb46c03428d53100c14010ee1365288842491020a63462620062911  
c228d0204802b36ca236095a8648cbb4618b4662c440821a890910024d24b245  
20122524c90588288cc9c04d5948220a276ec134644c90605b44508286494388  
0443b28c603080a2882d84a46d8ca629d0c68442064689885100a98d01498de4  
380da4068dd3947142b26c1a84611ba32842b42808a0711ac531e0a04c013765  
242862142890091061d940221b3360090292d02481200408491844a3222d5c88  
44149808a446610195640b390a0c9450ca406ad2b220c0380182308e13b90891  
8084148829c0189112350da02422e20406d9c2850428121cc989180272d24029  
c20812d8062a9994719bb8682384291a2289144511dc82445096450c4484c0b2  
049aa60543862c44326e88442120a84c9a3070e3b82d63268803254903438c48  
a809ca147253344e1243081ba704593022d99480e234228142129c302a943426  
6104452426281346094a326d11280918b82562281113410d41b21190844c8b12  
12a2c688c9c030220606d2188e848630904452128831d9207113c52843060e03  
3060cca6845826524c88011ef72562c85ffa43acfa49217f2b172d7bbc14620e  
6d980a71aabbdf0c45e9a206ecb1423fee15decc17601300149d9223cd6e6c6e  
1fa8e41fc7c64938ab68905fd3dcda50d87082e7d0d71d1bc9b2b84c85523ca8  
fe6cad294adf83be15b108ff721d0cc87bc3dd3a7590184b0e845663a91fc9e1  
c3c53a61d867420b04f092355753bc65a06368fd41295fd09924132c6f91f679  
64c142674a725c343914c4cecf58c074bcaf4558c97bf7911e07aa6d0938f2ee  
2bb3c1a8c595d635e84342fdea01dc24b211ad2fc281cf77e59110c7abc54bf0  
c86d480b9be276471dc9d603cee98cfab3e9fcfb703793560549ea4450fa7b3  
3fb9169c44b4d25fb9c457f49791cd3da03eac96095813c105132ccda4e63e49  
228cd23d8a1f37856f142d93b90db09f82af89258c63aab8047a80c036c9357e  
a2046f8dc6354f0c5295f342bb417d3cfeb0b1fd33622c29e14cbbd92e1363c6  
5ebd4504b7512329b9670e32e1b2c67a54e7f1a55f8b9f9ea04e8ca3a705e62a  
3c5e637374afb7aeb6dde612cde28f01a202d7aa4e34722d27dd3f9b89894d0  
19fd5d4d7119efe3723bba104cb8bb0981e074de3afe200daaaead826cc45f24  
4dbf431afab34efbdf782474d2fd57118f646214934ed99cba3b003e8d67a383  
6f6f19fc41910ce5163ee3ae99eb84d514eb761e63684ea56f9791d2dd4aac6e  
6168b948c817f75a222acb0e8cdc03cc4afe8f67157e1a363b7faeff9f172b98  
913677c5a1dd085e9ee4c22052c1af58193116673dcd3bfc5f34b855dcc6c778  
85649e9e71f43d4aea0f4b72ca7eda0578ba13d31a658d2d060a9a66ff69ed1b  
e7997a2fb1d2723d38f9bfabe18f8e7b3cda906e4e9b5e942c8eae296070ebf
```

```

d364947a940cc978bed66b37749e6d5dcd7be8c494440e2b84cecfefb98c0bed
fb3c41e3359d2cd7197f7be720c48aa6c6b6465c1ee63e3569c2adc744491370b
7f7826fe0b77a1d19d64101d032b918106b42d2ef73747e5601fe4ba50f23ede
521f031a817d15294a43722e8378784b6db0cf1ba9e8ae911d9201b9ce9cc301
9c6f5c27cb98da26144b64225a7c932b30f761e78a2d59a1d8b83ec6344a2f6d
d47e765706d00bf4a79a6a926c3ba91d812c8f2c797ab1796709e5d168567782
93529f0286d015c3b5399619642a333e9e593d6e3f5353994208e9e6a332851d
7f652522a928b917e27e2d6d42137dfe2ebfa6fb1c67b26c0254528685f7ebdb
e315a68eaa2da769e8a9f42d3e60007c71330926b2c0012d83ead4e4fd1ed872
ccd1972201d2b027f3545ac2d30cd78bc1d740fecbc6fc2a0446c6e30eac51f
5a69098aa2d447f2085b4e4e4b92ccc26921d2de478518cd090ce267aea2d27a
da57fd88b4976d89fb843cdccf49a76ca2679e6801bfa7fb031896fb50629704
b9923936bb5dd385311121cadfb11995e59b73034cf67ed03ab813867648d025
828087e949a9afd16b95d72d99b1edca257aac132ffb7a0709aed5a9c0ff05fb
0f2bbf28409eed7b5f5801be964ced019e1cb7851d3851f10290674e19fffb008
b301c4acf641a2bb14216e1d69cabf52b5ef227496b0f30799a855d117fad374
4a6fa33503ea798b52ddd7ee5426609dbfcd3f0c13b164d6c051f7ed4a119719
a712e388d328402081ff1354b554d2c237afed3b151c4ba8e9f4bdeb8499a306
6e26bbc69e8af089dec71731d1dc529eab17ef7374734c0fe475494c83836bdd
34a03b9bc89914716061bfb98ec6e61c3ed4438edcaf25243c647086b9ea7018
b0d9a8a0b00cecb00abde2498d69c2336101a772cbe4f571523f51bd05882cdf
358b849cc140aa1faf22423a12851ce0e33fd48975a4959fa5c5fe418c939081
91ab6e741b77bfe02cbd698ee795c466d615619e6441382c6eac01834ee9ab73
cea80bbe235c78da91bd79b6f82f899785d68700d393e675c2224d6b7a1ad213
20495679adaed70167b50866713a53109db7b6f7d81304ecdfd83b319b1ef248
306b45ad29e7ddcc863dac56048b5d69ea175011f7614c00a86a863cde1872a8
932878b9ac7e1ac5bda4997b72064f0cd75f4c814e034de11acb9013cf7ea926
b4e7eaace070c7ba2188efad2e431e1223d45dd05c4d8403c2e45cee6413ecbe
7527e873e455c4e610a61839aacc0bd56d2483e78f298b66a478eb2f558cbafc
a86be847baeb02c5b216c8cd88fea4df249b09e670a20703abac24b0a91abc4a
5646601442ba10becfd30993880051d07f56a05a9379e7a8e6befee3f22faa10
6398f7706006e42e9be1ef89d25c272f11a95095c587d713732284de9dbd3c72
17b0689e21d8eb0ff69668` }
    }
}

```

C.1.2. ML-DSA-65 Private Key Examples

Each of the examples includes the textual encoding [RFC7468] followed by the so-called "pretty print"; the private keys are the same.

C.1.2.1. Seed Format

```

-----BEGIN PRIVATE KEY-----
MDQCAQAwCwYJYIZIAWUDBAMSBCAIAABAgMEBQYHCAkKCwwNDg8QERITFBUWFxgZ
GhscHR4f
-----END PRIVATE KEY-----

```

```
SEQUENCE {  
  INTEGER { 0 }  
  SEQUENCE {  
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }  
  }  
  OCTET_STRING {  
    [0 PRIMITIVE] { `000102030405060708090a0b0c0d0e0f10111213141  
5161718191a1b1c1d1e1f` }  
  }  
}
```

C.1.2.2. Expanded Format

-----BEGIN PRIVATE KEY-----

MIIP2AIBADALBg1ghkgBZQMEAxIEgg/EBIIPwEhoPZGXjjHrPd24sEc0gtK4i19i
WUN9j1i1YeaWvUwn2FP6abgZkCPozWeN2fq/kEdkb/0Ms8x/eVgFpx5w0jcbBWPj
zTNGFJyMnrzyOwp0WpA06pxlYnkKfGPjhmPaot3bbkgNxAWh5wGUi3SEHvXMHD8r
8yeXLPuUQqzVN17MCFVxdxGHIiGGI4EABCR3gGFHUAdQFxcDVQRRUSVHGDgEYXVy
IkQQiGhghkYBJ0dWcYCHBmaGQzJEQSIENjhmDKCNjQkQyIFc2QQZFVUdyJ1VoFD
NhRiVQggZDdoVGh1Q1N1EGhxgzOAVHUFJYB1KBiE0BEIcmAgIAhYgwGDYROCghIG
FxFXh2h4iHhkN1RgF1cVUIRxiGYHJzKIBmR0GFZ2IYAxgnZkFXgkUCVZkMRNQ2
R4ASZnMUMBfMB1WGRxg2iGNQOEeGEQEGi1YRYTeGB4UyEkAHVHiCMENmYRZgQ1VB
goVgU2d4VjhDRDBjJhB3BzF4QnIUERZTA4UnaGdGAVCCNzUyB2YQdQRoEkGZgMD
JlIxJEVAiAaXgIh2chcwcYJHIVEngBF1RHSgyXIjM4CGYGRGg1IVhCA2gBGAIrGy
MxdzVFNIgQBEhlNnQ3BXclIDNGA4QjKfABAGBCYEJYRWAjVoIFGDhjhdJCEiQkVv
WFhncUvyhQR4hxcYBhiDYIaGQVZQgRZQJkZwBggmYic4MXJAclcwBycohiBmdYho
JgcGQCAzA0NmMVVGQkU0VmcYc0Vlg3AiUIRoViiAcDZwhGI3FxAAGVxdYR3hwhlVT
eCI1FEZ3KFZzAyKHABQzIGFxWEVSZjJQJLEzR3c4A1UWQxNHNrBmJ1F1dAJGiFw
Z0NGgYYBdlJFMzCHIQQ0NAEDIodjUVUmUIEwd0VEQWgVQYNjZBEgQCaHMENndxKA
iEY1VFMAYkWBBFg2USSEJ4A0UWZjWEN4VgFGURV0IyFDZoUiR3cxNFAXg2JCBVAA
ZIRHEjRAiABgRzVAV4MzYwghBhUiUgckiFE0hjcGdiJYhXEmVnNHaBZGRoQ1hwgS
JwVQCDgyACMggGY0UzYAM0aFckcGNVQANXcSJ1IwcUJTaHQ3RXAFZkMiRIKFIHIY
MzAgUzcZQHcnFU1MGNSUEBnM0YTGAcOBxckg3djRXMYWFFgIzNENiUWQzgWCFh3
NGJCiDAHA2WfNIUAdVixUDcCEYrjBdCIaAY2FQMADAENY1cIAhEGZHNGNSJiAzBD
gCEIUodXgyEHiGdICFY0dDZzQoQFhGaEFDcAVRCHNCZEdyESc4RzZSZHJXcUrwQX
hkQmAkcRrh0CBiH2gWEcXgTcGdoCBcFgYVYVHE2NCEHVYAWNYNYUyRA0EcRazh0Ji
gkd0E2VUQnBzRjV3dQBmJWJoQgISRoOGRhZkYDEiU4iEVACEVzRGR1RHJWBUYWaE
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C.1.2.3. Both Format

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8437d813b0f122f2fb17603b693ed9c38f17cfd50b815e6d9dfc0ed2ccf19f63
99274a1420f235a59d8bf724345e14e45d9e4be8934dfc3fa92678db61d7118b
f53cb8a2225b335f7eae50e3f941237628db76d8ea38f77a72af3a26c81fe435
23b335535a5d1db7c38f341082bb5734d089e8ae309cfda3a0bcb5cd5b097113
c8edf9616aa4f6e6631b9125276fb3f680a34341c3db668dc6cad45fc93b2708
ca2af75ccce734fd191c50089dad53982fddae02531ff93e1f21ff395fc0a128
74edf06b6f9647e95a7324586c71dfd91d901d621858190fecdd0ccd110bbac5
9f96cb884c3c93994748a56f41283bfc41fb89052153a894588c3cb9017f3d66
326c985637e575acb812346342654025d602de3ba940c19ac1a633dffda977b5
29b8013e19c1d6d0680f4dae62c924450ae66aab82f21473061dab3d62b247f9
07e3551939ad3f5465e9d08a82bfea17eea1b6b2b923757477f993000b2f43b7
0f28aaab1fe9a26ad1fd3361616c0b0e242fe76604b7033a1f30e97e28f526ca
3c880fe2b8d9d1b0c9ff188b31cb9d97425acab9b216d98a6ae355e583da71e8
864ee3d16b0759796190ef545c1e62bfef92af6ca147b13244d6c892fc8ef223
ab3f43f924c2f466097ee8` }
    }
}

```

C.1.3. ML-DSA-87 Private Key Examples

Each of the examples includes the textual encoding [RFC7468] followed by the so-called "pretty print"; the private keys are the same.

C.1.3.1. Seed Format

```

-----BEGIN PRIVATE KEY-----
MDQCAQAwCwYJYIZIAWUDBAMTBCKAIAABAgMEBQYHCAkKCwwNDg8QERITFBUWFxgZ
Ghschr4f
-----END PRIVATE KEY-----

```

```

SEQUENCE {
  INTEGER { 0 }
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
  }
  OCTET_STRING {
    [0 PRIMITIVE] { `000102030405060708090a0b0c0d0e0f10111213141
5161718191a1b1c1d1e1f` }
  }
}

```

C.1.3.2. Expanded Format

-----BEGIN PRIVATE KEY-----

MIITOAIBADALBg1ghkgBZQMEAxMEghMkBIITIJesvOwvJDBoaOL8zzwvX/Z153HX
q0G5A1jPp+k0yXEk20nuTpChbGAvXsm8OFF9ww4ynVqydn09hftJSDAPd20JiGdQ
tXwk2z/AEUye3111Mzc3T6cSSZFUmVJDSW0GN8s74FpZSCNb95h1+JbY/gyrMMhJ
SNtNYxWqrXyKxiQ2ZCIBSBYRCRes1AKJIKUsYrhFAEUqCJZwkBJuFJNw1EYQHERR
WJaRDkKpgrJBByqhxxChoBJaJSECFmyJthChkWRJBnLiRhASJRJAfyzRioIaQQCaS
IJKpEwVpXDRopDKOGSasWUYQCaRJi0JNEjZhWBB1ASiQGjNMmYyX06JJCyi1QxQo
wDiBAXVNWyIGCiDIIZFS1CiLw8BNpJghmEAg0UKGy0BwW7BxnJYswRIGU0YJDEUC
FEZukbQhVLCM5EZCmiCMASE1E0EFWkAiE8kMoBhAUswIwyzQsS8hoG6RgSYSEYzAp
SqBpW4AE0jgKFCZM4rJEi6IRJEZJxBRSC0JxA7IQkiiAASSI4wgRCgUoGcSBACai
3ERoQhIiRAAqySZqDiCcx4MBEmRSEGDYNETdCIhiMY7KRDJgIoaABCJJEBBMkXJhx
goRxdJSubAxnEIuGqgoAgIRAcJC8cFiiR1IsJkTIIrXIJoE6VkUCCGIQqCKZRE
SCIwIj1KApiECaKIGRkpREiMIpUMoQRyBIdwEiEQGaEG0mFiQZK0zYI28BAWLZR
DKcJjCRhmZBkjmKQWysQEKNJAyVhQzKKEZHEyLiGbdhBEEcsGcZEHCUsBIgw2UZp
myAAG0aCwQSAW6BJGJAlACaC8IxWkByVMYgwbAxJLFNEJUoFAAKoMhNVKKII5iB
YJAEAhYsEyFAkYaNCMKRkrQm0LQMCcZgUUQuBBEmACKrk8IIY6QxIgAowRQIDEAs
QRQGNcByVCIGiwhNoUhpEDBBHChJRBi0zJZI2UJQGwZJDEWIIwQNIDAuI4UsFACw
QLaFTMAgRIYgQGBsVAJIZIhsWQYySRSEBMDQE0ko5AYJ08YQyChMIz1EUqRkzKhJ
RDgyComEADQsIoWNEDEJCTJlHIMMQEApIYUACaFthMBk4gItSARAEgm04EIuk0QI
EhBqAYQFkjCKyzS0oiYuXIYRCzUIGBAAAjQmJC0J0YQAJEZge7JJJChGGAJxoDiQ
iRRe05YtoxAIychwBhQ8gEQUKNXCZBRKJtSBIOQDILCxSCCKguy4KIA6NgGyUm
jLggJLCFmAQhCKcsghzKJJAQQBIOmEApVp0aRNE6QMkUYNYZSAKDhFXMZQARcg
U8YomxgQQRJokBIhwBCEQhaSU4IpgSZJ2KQFmiYkJAMP4EAm0gJIESRoEZmJmBSF
ySANUBKMHAgQAhaAAJUowSiQWbSF0xRlCkBuES1lGMJMITR12DBpEDBSGTFmjBiK
yMAITJgwo6YgQRYiGAUuIiUqZLg1CrMBYyCECYAJGSg0AheBo5QR45hsWCAhCUEQ
YDYiCAZxESKFWqCFwMaEXDgGy7ZpFISEUyKCoaZaZiYAXCYioKgImDRy1CBBQ8SQ
SBZoGxZSGjcCUCBCSEiKIBFB4gBswMIMFAZJETFNGQYKiUYJG4FLRMgAggZwABZy
zCRQikKJnJaQZChwkrJomCZiYZRAwRaJ2EJkGiFOYpBkIcgkiyhtXEKSoMZNDIWA
zIhN1EKNQjSKCwRRwyaGJCWBEjUGoEEQyJSBW7QxHAgGXCQIAydaqIMi14YQCGBRt
o0YMSxhgUMYsG5ItERUEogAEIUgu2BYG0hCKg6l1CDENCThr2UhJcXZMIz1lGRKc
SkJ0bIhC4MsIyWFKxaFRKBEG4NQAIjYsSwSamxRlIZNgGBMK2UYNIkVhyLRAoUit
ArgJABREm7YRC5eMQBBKghRq2pAFHAKODBlYo7SNJDBQEYcJZMYo5BiSmLrsYRZR
QEYOHDI2iBRiDaKI7EhgpAoGhUy4hHHkgSOE7aQExNoyYRoTEbtCzMAgUZN0jgM
BJaBpIhQAPCFIRAE06Rx0oAQypZAUaZBpIQo4AhSCzCM0jgKDC1Rw4IJyiCR2DaS
o6YokLiOhYBGjSGN9mmWRaYgewhz0gRhp0dfx0fBTfpxGEWFQF/ReAivHgYjnt
s05ayovxNpZ3tEescYrEfYUMTXewvjHcn1C00XjyQnSrAYX3J6vf9Z9EkDcb8EYQ
42TmTsh1750g3JQHfh4WYyeoebirUWFGsqP3dDe5s8x9F66t3ITbYnRqNawJb3gv
YqfWGqbWaT3uyQsjxmmFoCMH4KHK5ZimcyTboPUvIkMidekyVwZc035eHP4d/U0N
8IbfISQ0FKLSfiAjCoKb50tMgsFtNfeLD14ZgzLgAHS7ZGEVqxUyJccto5e2rA2
nxFxs0aavY0E4t1VPxt454bh7p0LmN0fg8zs830evTqdY67HZhZKEBcaT9jGPa8Y
LEISWMX1KapVy3664uFlIXxh9x6KdBMUENAYR+3hHTTbkfbwiqJHj9eJZ5wE1J9x
vAFx4H46i7V1PbvapBGmNQq0bu+/hvXVHCnv5M3XZh1c9sPbItD03eWZhURZ2X8g
33RVvfnWoZjQ9+ttNBEfyUCyXAVDt4jt2p0mgQ6sPWzJxRMnws+D6IfUCJ4ZaV4R
rdg39vRAzDYPk/Mv7oqWY3Esa704yEq3tUgj7DY+tt+QutZ/B/OYPvVUwez7IX9na
8yBte0s5F/HIt6kuPGfYmID98uR/WgyZRZXBfwr0G6v1o1tNwcQt1qnbJx52TeL7
AVpJqFDHkZvKcaAjNuLjJf310sWZVU0KfEvRexAw51rr/MRvu512J4CrTh0vkvs
CukZT17d2qZ1B3YRbp8nD3dxSteo6Jr090t/99jb7Cf4AgqYUkfizazvSJSk1ouj
fKkS1r5zUByzUYHl1t3cJNQs2Mdo3AOE/02bhMb8Gs262sDRQkyCfCnvv+uH92HWW
BofBFjw1PX0qyQk3s06XjpL4Ia3JZiIC70iaF+e7Za4X2DuQ275qUBp0E0W+50W1
tTry5bo9HvP04FrFczpM8uUwNg/uZJKZArVx9v0uMFZSpMsBD3n4FeGPK7uMyJ+m
/Hb3fInik88XWgsZWAD+ctLM3X115b2QvGrENDakQ0+FLpocjFPeA78ZM2XXNary
nFFiphfjZ0f5RBA ND7SP70BVj0VC18w91QhmLPI/uI4ZVKpF0cXhFbzDbwWz4JjV
VSIPQL4mKbNFB7hGTFTCe13seNqPImUFFHl6+Go1Ery34pIzee9tc8E3AGwb0PUe
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B1IpNf1mXqeCLZMPI+q/9407I211aeIEuUMUHGDaiBCVa+BSU2Xbq1TtSMt21kzN
9cvTrucoLUoAANJ4TXuPqxay9/DVilcyse+8TrHP7etD/eebaezA++qh5rQHKGc7
1LLpig1KjwL4U5UHMPKNnesS/MeXaljhjkvaDlijMaL3HXzMLUUbMrHGXDQeqz0fu

```
UTsh1UxBwAyHOHLu1M8U9GA3Q1Nh9L21SCH3EUYM666MB1CKkhn4j6a+2qZ47tUB
1EoWrm97W7ei4eNX5w17mEYaLHHLd6di1q2YJAgdN/KS/UvouEw2EQ3HRDYCAB7r
4L1snQXoaSVtL/P51Re379KjN3QFbLVnFnWotJLp9fJiDrjvk4HT0d8Zk4t7X/qs
WbyBEPqHuo16PQF1+0Qd0PgE8Rud7Q81K114NdBjB6jgXu9NIZBD0eHPRYKjo+ie
A12UU0c2bALz3WNo10R+hdPSqXBb1X1hhS5aV5+TscUUxTn0nqEWOipJ0w78tH9H
SPapnC/cHgoLkr0GBNuKos+4K0A3N0z7z514bgVconWJGetSIug0SsukKHt7cvc
kx3BcpjM73ZkXH0zCgXCzkD4m4VGjzV6IXdR4VRjEwTsTgS7RbNniQnHSvUc43A2
TY9PfrHmHgAodCnJl3oMiypomKbEwnYA0krwdxQVdzH1/M4ZusM/Y1JA1DUj/yo
Ai9JKQ4tU3YWL7qpqtFkU8gls19lFWNeqSvqcjZ7q1TeP56uppVCqBpBJ/ccuqJX
8yT+/vFPCPvWWgSc0vs2JZSo4j/xomF9tbFY9vAc9Qqw7ZXG5wmEEWQQiwbhtAqw
qxHECDAdPZ20pp6WipYAs9F/OAEc4oB04sLhC/YZfGAtjQzn06PvLYli08nxLqM4
eR6SZruM4CsSTGx5KbrqATJECYRUoIDrdSPH07G3xbZ3X6urq76Qdf5Wh6pFE5e7
nPzNBRJD6b9a7yQGLTnd5fziTp3b3hGRBS2Aw235+ENIcvJ37U9aH0jr07lggkp0
TxABsEy2hfm+5NDdsMVxWYrCAhpmBv0jNFxvu4TwzgX+UnNFIbewfGOI0605kxi/
ATFQsqnfuvVI+dMqnNTGiTuksRMwoT0q0+0qWJZuuwE0R11UP9d5evVJ9Wjq6+1X
9k/shU0kCuXVYdWmG1G6jq3o1HLvqEaaHvUP10L2JzSyrph1SGDdJk06LkiGe01
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hTQg5NGnGuYv+Qyhk83WwvS+0mNBWq+aNQLLwqIuKmY8dkUAHNGQt7wXx1/q346H
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vxdtShi6KJWnu0tHREqbqNu0wSTNQbuzL0vLHeSMSrtRBgegAbWgALukNhi2wZ5D
UXtFtCQfKotnxx0IGFI606Q1EcJxb/nNMyA0tnK1L/FmEIBc2+dUSoqEtm4cdFpz
wba821t3uVHzbA96U3Lenl0fm7zeiEPGkJAC3aSHXmdXGvC+xYGFbDLAnCQ0Zk52
H1fNDY3Ipxy5GKV2LREShc2LVhPdvQygisA0Kyve44+W+nVLSrCHF5wRPJOYaoED
VuuUVAuTy53sSqkpD/EuwaouZWyb49WQdTw2bGAUBsBhvCID0h/R90ERHQ0biB05
g8tQbD6n/zBXmD6L8BaC+7APQwBTE8gsE5KRimFloTM4/+EamSwfs9EDKqZ5pBjI
uk+KC8GZ4Qz2vXehT91qBgk1FDS00o10Q00roo2djaca+LPk0Zys0P84ErGsi4M9H
VovEXXCmjmjGSAADCuIYWQwaQ356I6V0/kT2cIbraXufpXg18Lj3DwqSkibvszba
4hgzoCghjNY3MsgKpHfmLRQduoGFT3DaaNr/SoTLbed5JU6K1+c1ZTdK9Akq8Fy9
Z1Svw/1y8K4jJpXLZmjQ/sxAab2Qu1KLg++i+829k7KJkpYh7XTYCHOPwQPusQVR
CFH8kxnxceoM7QuXtbn7XvmFGGvFIJj560dvZ7fMdmXUdYeXXLRaUPxkEAcZv3Y0
Xw/fHgnv6fuAdcEU5Gvgh5oZXMBoc0I9JjHa5xw5lEgch2HEDQfFv8qV5xi3siWF
rwPtNBdaRtV681G0Mqf8GqRIJzKoGof3JPjS54Czo51FGjgPdcLWgMxyE+qx1KWd
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F7jk5ksZPxqsUjqt8nSKndj/vCn01Fe2+XgbCKZ6GXXQMczXFUXAA3Q0BWwkNNE+
bEvuv0b8EiIsCy7M1hWdWuq0VU16CWUrBr98ppmnGZ5xbQXdtVTBBqPKzA9I2qbq6
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V+jKe+9YVfK4E+0vTECURaMxfJvho1ri+00rh5IbkEvywU21FM7gRSuc/CdjdnSv
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VBSfFKwjPNTzoit/uPCTJb8qzo07a124oSGitoIummkTHMz1IimECxE/x7C8xYQF
v+h/H5X/wulvxV1lZ+1DZN+qbZ1abrma5N30JA==
-----END PRIVATE KEY-----
```

```
SEQUENCE {  
  INTEGER { 0 }  
  SEQUENCE {  
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }  
  }  
  OCTET_STRING {  
    OCTET_STRING { `9792bcec2f2430686a82fccf3c2f5ff665e771d7ab41  
b90258cfa7e90ec97124d8e9ee4e90a16c602f5ec9bc38517dc30e329d5ab276  
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4991549af243496d0637cb3be05a5948235bf79875f896d8fe0cab30c84948db  
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4840859b226d1c28645912419cb891840489449005cb3462a086904026922099  
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334c998631d3a249098225431428c0388103154d5b2886088748233152942225  
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681b16521a370250204248488a201141e2006cc0c20c14064911314d19060a89  
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619440c11689d842641a214e62906421c8248b286d5c4292a0c64d0c8580cc88  
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21482ed81606d2108a83a22508310d093851d948490b164c2332251919024a44  
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ca964051a641a48428e008520b308cd2380a0c2951c38209ca2091d83692a3a6  
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```

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C.1.3.3. Both Format

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6M2LVMNwh6nhREBZXmkI0u7b/MZT4C/fdx9wGnm55aJu0K1HhCBw87VwF0IhEhnn
YXYsN/DQodG5dQ/uV34SCBFcZqwH7Akeaj/Eqmol08uoa03TFU3K9RYvYV6FSQps
o0LzTE0sYaPqa/7v2FDhk0sdjaTSi1706xZ4wCQz7NXUiU2QEJX6Mp771hV8rgT
7S9MQJRFozF8m+GjWuL7TSuHkhuQS/LBTbUUzuBFJRz8J2N02xXJneoVrN4ZfG61
JJi00bYyh764Z2h1qq060bQ7jKsVy/J6SYdZ4yA6vzaelyQvCwFUFJ8UrcM8230i
K3+48Jm1vyr0g7trXbihIaK2ghSaaRMcz0UiKYQLET/HsLzFhAW/6H8f1f/C6W/F
WWVn6UNK36ptnVpuuZrk3fQk
-----END PRIVATE KEY-----
```

```
SEQUENCE {  
  INTEGER { 0 }  
  SEQUENCE {  
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }  
  }  
  OCTET_STRING {  
    SEQUENCE {  
      OCTET_STRING { `000102030405060708090a0b0c0d0e0f1011121314  
15161718191a1b1c1d1e1f` }  
      OCTET_STRING { `9792bcec2f2430686a82fccf3c2f5ff665e771d7ab  
41b90258cfa7e90ec97124d8e9ee4e90a16c602f5ec9bc38517dc30e329d5ab2  
7673bd85f4c9b0300f776389886750b57c24db3fc012e61ede59753337374fa7  
124991549af243496d0637cb3be05a5948235bf79875f896d8fe0cab30c84948  
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6ada90051c028e0c1972a3b48d24305011870964c628e4189298b46c61165140  
460e1c3248da205188368a23b1218290281a1532e2186192048e13b690131368  
c984684c406d0b330081464dd2380c049681a4885002908522b004d3a471d280
```

10ca964051a641a48428e008520b308cd2380a0c2951c38209ca2091d83692a3
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24b11330a2d3aad3ed2a58966ebb0134465d543fd7797af549f568eaebe957f6

```
4fec854674902b97558756986946ea3ab7a251cbbea11a687bd43f5d0bd89cd2
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10805cdbe7544a8a84b66e1c745a73c1b6bcd5b77b951f36c0f7a5372de9e5d
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fa754bb2b087179c113c93986a810356eb94540b93cb9dec4aa9290ff12ec1aa
2e656c9be3d590753c366c601406c061bc22033a1fd1f4e1111d039b8813b983
cb506c3ea7ff3057983e8bf01682fbb00f43005313c82c1392918a6165a13338
ffe11a992c1fb3d1032aa679a418c8ba4f8a0bc199e10cf6bd77a14fdd6a0609
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e8ca7bef5855f2b813ed2f4c409445a3317c9be1a35ae2fb4d2b87921b904bf2
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1ccce52229840b113fc7b0bcc58405bfe87f1f95ffc2e96fc5596567e94364df
aa6d9d5a6eb99ae4ddf424` }
    }
  }
```

C.2. Example Public Keys

The following is the ML-DSA-44 public key corresponding to the private key in the previous section. The textual encoding [RFC7468] is followed by the so-called "pretty print"; the public keys are the same.

```
-----BEGIN PUBLIC KEY-----
MIIFMjALBg1ghkgBZQMEAxEDggUhANeytHJUquDbReeTDUqY0sl9jxOX0Xidr6Fw
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/NdtmQt/qZzUWv24g21D5Fn1GH3wWEeXCaAepoNZNfpwRgmQzT3BukAbqUurHd5B
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GYRsrBjJiQpdoRME0VWuiFbWnGeWdDGsq1t0YWQcf3MLN51JKe+2uV0hbMY6FTo/i
svPt+s1xkSgnCq/R5QRM0k/a/Z/zH5B4S460RZYUSg2vWGUR09mWK56pWvGXt0X8
YPKx7RXe0lvvX4m9x52RBR2bKBbnT6VFMe/cHL501EiFf0drzVjyHAt10zt2p0B2
plWaMCcYVvZGP3SFmqukl8C0GHKjND3utsocfZ9VTJtdFETWtRfShumKj7ssij
DuyTku8/l3Bmya3VxxDMZHsVFNIx2VjHAXw+kP0gwE5nS5BIbpNwoxoAHTL0c5ee
SQZ0nn5Hf6C3RQj4pfi3gxK4PCW90IygsP/3R4uvQrcWZ+2qyXxGsSlkPlhuWwVa
DCEZRTtzbmdb7Vhg+gQqMV2YJhZNapI3w1pfv0lUkKW9TfJIuVxKrneEtgVnMWas
QkW1tLCCoJ6TI+YvIHjFt2eDRG3v1zat0jcC1JsImESQcMGDM5e8RBmzDXqXoLOH
wZEUdMTUG1PjKpd6y280p122W70eWecB52lX3vby1EVZwxp3EitSB001whnxaIsU
7QvAuAGz5ugtZUPpwOn0F0TNmBW9G8iCDYuxI/BPrNGxtoXdWisbjbvz7ZM2cPCV
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Er2U1wo23TS1FKhnkfDrNvAUWwmrZGUbSgMtSplhGiocSIkWJ1mHaKMRQGC6RENI
bfUVIqH0iLMJhcIW+ObtF43VZ7MEoNTK+6iCooNC8XqaomrljbYwCD0sNY/fVmw/
XWkkKFZ7yeqM6VyyqDzVHsWv6jz0aJQq0388gg76077wQVeGP4VNw7ssmBWbYP/Br
IRquxDyim1TM0A+IFaJGXvC0ZRXmfkHZEK8J7/9zkwmrWLKaFFmgC85Q00k4yWeP
cus0TuX9quZtn4Vz/Jf8QrSVn0v4th14Qz6GsDNdbpGRxNi/SHs5BcEIz9asJLD0
t9y3z1H4TQ7Wh71errHFM8BvDZcCPZKnCCWDe1m6bLfU5WsKh8IDhiro8xW6WSXo
7e+meTaaIgJ2YVHxapZfn4Hs52zAcLVYaeTb14TPBcgwsyQsgXI=
-----END PUBLIC KEY-----
```

```

SEQUENCE {
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
  }
  BIT_STRING { `00` `d7b2b47254aae0db45e7930d4a98d2c97d8f1397d17
89dafa17024b316e9bec94fc9946d42f19b79a7413bbaa33e7149cb42ed51156
93ac041facb988adeb5fe0e1d8631184995b592c397d2294e2e14f90aa414ba3
826899ac43f4cccacbc26e9a832b95118d5cb433cbef9660b00138e0817f61e7
62ca274c36ad554eb22aac1162e4ab01acba1e38c4efd8f80b65b333d0f72e55
dfe71ce9c1ebb9889e7c56106c0fd73803a2aecfeafded7aa3cb2ceda54d12bd
8cd36a78cf975943b47abd25e880ac452e5742ed1e8d1a82afa86e590c758c15
ae4d2840d92bca1a5090f40496597fca7d8b9513f1a1bda6e950aaa98de46750
7d4a4f5a4f0599216582c3572f62eda8905ab3581670c4a02777a33e0ca7295f
d8f4ff6d1a0a3a7683d65f5f5f7fc60da023e826c5f92144c02f7d1ba1075987
553ea9367fcd76d990b7fa99cd45afdb8836d43e459f5187df058479709a01ea
6835935fa70460990cd3dc1ba401ba94bab1dde41ac67ab3319dcaca06048d4c
4eef27ee13a9c17d0538f430f2d642dc2415660de78877d8d8abc72523978c04
2e4285f4319846c44126242976844c10e556ba215b5a719e59d0c6b2a96d3985
9071fdcc2cde7524a7bedae54e85b318e854e8fe2b2f3edfac9719128270aafd
1e5044c3a4fdafd9ff31f90784b8e8e4596144a0daf586511d3d9962b9ea95af
197b4e5fc60f2b1ed15de3a5bef5f89bdc79d91051d9b2816e74fa54531efdc1
cbe74d448857f476bcd58f21c0b653b3b76a4e076a6559a302718555cc63f748
59aabab925f023861ca8cd0f7badb2871f67d55326d7451135ad45f4a1ba6911
8fbb2c8a30eec9392ef3f977066c9add5c710cc647b1514d217d958c7017c3e9
0fd20c04e674b90486e9370a31a001d32f473979e4906749e7e477fa0b74508f
8a5f2378312b83c25bd388ca0b0fff7478baf42b71667edaac97c46b129643e5
86e5b055a0c211946d4f36e675bed5860fa042a315d9826164d6a9237c35a5fb
f495490a5bd4df248b95c4aae7784b605673166ac4245b5b4b082a09e9323e62
f2078c5b76783446defd736ad3a3702d49b089844900a61833397bc4419b30d7
a97a0b387c1911474c4d41b53e32a977acb6f0ea75db65bb39e59e701e76957d
ef6f2d44559c31a77122b5204e3b5c219f1688b14ed0bc0b801b3e6e82dcd43e
9c0e9f41744cd9815bd1bc8820d8bb123f04facd1b1b685dd5a2b1b8dbbf3ed9
33670f095a180b4f192d08b10b8fabbbdfcc2b24518e32eea0a5e0c904ca84478
0083f3b0cd2d0b8b6af67bc355b9494025dc7b0a78fa80e3a2dbfeb51328851d
6078198e9493651ae787ec0251f922ba30e9f51df62a6d72784cf3dd20539317
6dfa324a512bd94970a36dd34a514a86791f0eb36f0145b09ab64651b4a0313b
299611a2a1c48891627598768a3114060ba4443486df51522a1ce88b30985c21
6f8e6ed178dd567b304a0d4cafba882a28342f17a9aa26ae58db630083d2c358
fdf566c3f5d62a428567bc9ea8ce95caa0f35474b0bfa8f339a250ab4dfcf208
3be8eefbc1055e18fe15370eeeb260566d83ff06b211aaec43ca29b54ccd00f8
815a2465ef0b46515cc7e41f3124f09efff739309ab58b29a1459a00bce5038e
938c9678f72eb0e4ee5fdaae66d9f8573fc97fc42b4959f4bf8b61d78433e86b
0335d6e9191c4d8bf487b3905c108cfd6ac24b0ceb7dcb7cf51f84d0ed687b95
eaeb1c533c06f0d97023d92a70825837b59ba6cb7d4e56b0a87c203862ae8f31
5ba5925e8edefa679369a2202766151f16a965f9f81ece76cc070b55869e4db9
784cf05c830b3242c8312` }
}

```

The following is the ML-DSA-65 public key corresponding to the private key in the previous section. The textual encoding [RFC7468] is followed by the so-called "pretty print"; the public keys are the same.

-----BEGIN PUBLIC KEY-----

MIIHsjALBg1ghkgBZQMEAxIDggehAEhoPZGXjjHrPd24sEc0gtK4il9iWUn9j1i1
YeaWvUwn0Fs427Lt8B5mTv2Bvh6ok2iM5oqi1RxZWPi7xut0ie5n0sAyCVTVchLK
xyKf8dbq8DKovVFRH42I2EdzbH3icw1Ze0VBBxMWCXiGdxG/VTmgv8TDUMK+Vyuv
DuLi+xbM/qCAKNmaxJrrt1k33c4RHNq2L/886ouiIz0eVvvFxaHnJt5j+t0q8Bax
GRd/o9lXotkncXP85VtndFrwt8IdWX2+uT5qMvNBxJpai+noJQiNHyqkUVXWyK4V
Nn50sAO4/feFEHGULzn5//CQI+r0UQTSqEpFkG7tRnGkTcKNJ5h7tV32np6FYfYa
gKcmmVA4Zf7Zt+5yq0F6GcQIFe9LKa/vcDHDpthXFhC0LJ9CEKWoJx1+FoErAxFZ
tluWh+Wz6TTFilrpinm6c9Kzmdc1EO/60Z5TuEUPC6j84QEv2Y0mCnSqghP64kmg
BrHDT1uguILyY3giL7NvIoPCQ/D/618btBSgpw1V49QKVrbLyIrh8Dt7KILZje6i
jhRcne39jq8c7y7ZS0sFD4lk9G0eoNDCpD4N2mGCrb9PbtF1tnQiV4Wb8i86QX7P
H52JMXteU51YevFrnhMT4EUU/6ZLqLP/K4Mh+IEcs/sCLI9kTnCuAovv+5gSrtz
eQkeqObF038AoNma0DAeThwAoIEoTa/XalWjreY00kDi9sMEeA0ReeEfLUgnHXP
KKXgHHeZ2VghDdvLIm5Rr++fHeR7Bzhz1tP5dFa+3ghQgudKKYss1I9LMJMVXZs
j6YBxq+FjfoyrISrsqKYh/kDNZSaXW7apnmIKjqV1r9tIwoiH0udPYy/OEr4GqyV
4rMpTgR4msg3J6XcBFwflq9B2KBTUW/u7rxSdG62qygZ4JEIcQ2DXwEfpjB1hyrT
NNXN/7KyMQUH6S/Jk64xfal/TzCc2vD2ftmdkCFVdgg4Sf1TskbX/ts/22dnmFC1
rUB0ZBR/t89Pau3dBa+0uDSWjR/ogBSWDc5d1CI2Um4SpHjWn1++aXAXCzCMBORQ
GM/HsqdDCh0msax7sCzMuZ2RGsLxEGhhP74Cm/30As9c04lQ7XLIOUTt+8dWFa+H
+GTAUfPFVfBFQShjpAwG0dq1Yr3/BXG4080Re70wCIC7pemYI5uV+pG31kFtTzmL
0tvNMJg+01krTZ731CNv0A9Q2Yq10iNaxBcnIPd9lhcmcpGM/o/3pacCeD7cK6Mb
I1kBWhEvx/RoqCL5RkA5AC0w72eLTLeYvBFiFr96mnwYug03tY/QdRXTEVBj02FL
56B+dEMAdQ3x0sWHUziQWer8PXhczdMcB2SL7cA6XDuK1G0GTvNBpVc3Ryn8TiLT
YuK1GRIEUwQovBUir6KP9f4WVeMEylvIwnrQ4MajndTfKJVsFLOMyTaCzv5AK71e
gtKcRk5E6103tI/FaN/gzG60FrrqBeUTVZDxkpTnPoNnsCFtu4FQMLneVZE/CA0c
QjUcWeVRXdWvjgiaFeY16Pbe5jk4bEZJfXomMoh3TeWBp96WKbQbRCQUH5ePuDMS
C0/ew8bg3jm8VwY/Pc1sRwNzwIiR6inLx8xtZI04iJCDrOhqp7UbHCz+birRjZf0
NvvFbqQvrpfpmp6wRSGRHjDZt8eux57EakJhQT9WXW98fSdxwACTjwX0anSY/utQH
P2qfbCuK9LTDmQEDoM/6Xe6y0GLKPCFf02ACa+ffFk9KRCTvdJSIBNZvRkh3Msgg
LH1UeGR7TqcdYnwIYCTMo1SkHwh3s48Zs3dK0glcjaU7Bp4hx2ri0gB+FNGe1ACA
0zT321Lp9aWZBDnK8I0pW4M/Aq0QoIwabQ8mDABYhb1KL0dw01rvR1KH010xisI1
FDFiEP9WaBSxD4eik9bxmdPD1ZmQ0MEmi09Q1fn877vyN70MKLgBgtZ1l0HxTxC/
uyG7oSq2IKojlvVsBoa06pAXmQIKIWsv6K12xKkUju+ahqNjWmqne8Hc+2+6Wad9
/am3Uw3AyoZiYnLzC44Burjwi0kF6EqkZBvWAKEM2XUgJl8vIx8rNeFesvoE0r2U
1ad6uvHg4WEBCpkAh/W0bqmIsrwFEv2g+pI9rdbEXFMB0JSDZzJlTasuEPS6Ug9r
utVkpCpV4nvbCA99IOEylqMYGVTDnGSc1D6+F99cH3quCo/hJsR3WFPdTWskDQCL
avXozTG+aaKpbU8/017YbyIeS5P2X1kp1nUzYkuSNXUMMHB1ULWFNtEJpxMcWlu+
SlcVVnwSU0rsdmB2Huu5+uKJHHdFibgOVmrVV93vc2cZa3In6phw7wnd/seda5MZ
poebUgXXa/erpazz0vtZ0X/FTmg4PWv1oI6bZtpT3N4Ai7KUUFgr0TLNzEmVn9vC
H1JyGIDIrQNSx58DpDu9hMTN/cbFKQBeHnzZo0mnFoo1Vpul3qgYlo1akUZr1uZ0
IL9iQXGYr8ToHCjdd+1AKCMjMLUvvehryE9HW5AWcQziqrwRoGtNuskB7BbPNlyj
8tU4E5SKaToPk+ecRspdWm3KPSjKUK0YvRP8pVBZ3ZsYX3n5xHGWP0gbIQS8RgoF
HgLy6ERP

-----END PUBLIC KEY-----

```
SEQUENCE {
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
  }
  BIT_STRING { '00' `48683d91978e31eb3dddb8b0473482d2b88a5f62594
9fd8f58a561e696bd4c27d05b38dbb2edf01e664efd81be1ea893688ce68aa2d
51c5958f8bbc6eb4e89ee67d2c0320954d57212cac7229fff1d6eaf03928bd515
11f8d88d847736c7de2730d5978e5410713160978867711bf5539a0bfc4c350c
2be572baf0ee2e2fb16ccfea08028d99ac49aebb75937ddce111cdab62fff3ce
a8ba2233d1e56fbc5c5a1e726de63fadd2af016b119177fa3d971a2d9277173f
ce55b67745af0b7c21d597dbeb93e6a32f341c49a5a8be9e825088d1f2aa4515
5d6c8ae15367e4eb003b8fdf7851071949739f9fff09023eaf45104d2a84a459
06eed4671a44dc28d27987bb55df69e9e8561f61a80a72699503865fed9b7ee7
2a8e17a19c408144f4b29afef7031c3a6d8571610b42c9f421245a88f197e168
12b031159b65b9687e5b3e934c5225ae98a79ba73d2b399d73510effad19e53b
8450f0ba8fce1012fd98d260a74aaaa13fae249a006b1c34f5ba0b882f263782
22fb36f2283c243f0ffeb5f1bb414a0a70d55e3d40a56b6cbc88ae1f03b7b288
2d98deea28e145c9dedfd8eaf1cef2ed94a8b050f8964f46d1ea0d0c2a43e0dd
a6182adb4f6ed175b6742257859bf22f3a417ecf1f9d89317b5e539d587af16
b9e1313e04514ffa64ba8b3ff2b8321f8811cb3fb022c8f644e70a4b80a2fbfe
e604abb7379091ea8e6c5c74dfc0283666b40c0793870028204a136bf5da9568
eb798d349038bdb0c11e03445e7847cb5069c75cf28ac601c7799d958210ddbc
b226e51afef9f1de47b073873d6d3f97456bede085082e74a298b2cd48f4b309
3155f366c8fa601c6af858dfa32c08491b2a29887f90335949a5d6edaa679882
a3a95d6bf6d970a221f4b9d3d8cbf384af81aac95e2b3294e04789ac83727a5d
c04559f96af41d8a053516feeeebc52746eb6ab2819e09108710d835f011fa63
065872ad334d5cdfb2b2310507e92fc993ae317da97f4f309cdaf0f67ed99d9
0215576083849f953b246d7fedb3fdb67679850a5ad404e64147fb7cf4f6aedd
d05afb4b834968d1fe88014960dce5d942236526e12a478d69e5f6e6970310b3
08c06845018cfc7b2ab430a13a6b1ac7bb02cccbb3d911ac2f11068613f6e029
bfdce02cf5cd38950ed72c83944edfbc75615af87f864c051f3c55456c541286
3a40c06d1dab562bdf0571b8d3c3917bbd300880bba5e998239b95fa91b7d64
16d4f398b3adbc30983ed3592b4d9ef7d4236fd00f50d98aa53a235ac417272
0f77d96172672980cfe8ff7a5a702783edc2ba31b2259015a112fc7f468a9c2f
9464039002d30ef678b4cb798bc116216bf7a9a7c18ba03b7b58fd07515d3115
049d3614be7a07e744300750df1d2c58753389059eafc3d785ccdd31c07648be
dc03a5c3b8ad46d064d59c13d57374729fc4e295362e2a5191204530428bc152
2afa28ff5fe1655e304ca5bc8c27ad0e0c6a39dd4df28956c14b38cc93682cef
e402bbd5e82d29c464e44eb5d37b48fc568dfe0cc6e8e16baea05e5135590f19
294e73e8367b0216dbb815030b9de55913f08039c42351c59e5515dd5af8e089
a15e625e8f6dee639386c46497d7a263288774de581a7de9629b41b4424141f9
78fb8331208efdec3c6e0de39bc57063f3dcd6c470373c08891ea29cbc7cc6d6
483b889083ace86aa7b51b1c2cfe6e2ad18d97ce36fbc56ea42fae97e6a7ac1
14864478c366df1ebb1e7b11a9098504fd5975bdf1f49dc70002b63c1739a9d2
63fbad4073f6a9f6c2b8af4b4c332a103a0cffa5deeb2d062ca3c215fd360026
be7c5164f4a4424ef74948804d66f46487732c8202c795478647b4ea71d627c0
86024cca354a41f0877b38f19b3774ad2095c8da53b069e21c76ae2d2007e167
19ed40080d334f7da52e9f5a5990439caf083a95b833f02ad10a08c1a6d0f260
c007285bd4a2f47703a5aef465287d253b18ac22514316210ff566814b10f87a
293d6f199d3c3959990d0c1268b4f50d5f9fcefbbf237bd0c28b80182d665974
1f14f10bfbb21bba12ab620aa2396f56c0686b4ea9017990224216b2fe8ad76c
4a9148eef9a86a3635a6aa77bc1dcfb6fba59a77dfda9b7530dc0ca8648c8d97
3738e01bab8f08b4905e84aa4641bd602410cd97520265f2f231f2b35e15eb2f
a04d2bd94d5a77abaf1e0e161010a990087f5b46ea988b2bc0512fda0fa923da
dd6c45c5301d09483673265b5ab2e10f4ba520f6bbad564a5c3d5e27bdb080f7
d20e13296a3181954c39c649c943ebe17df5c1f7aae0a8fe126c477585a5d4d6
48a0d008b6af5e8cd31be69a9296d4f3fd25ed86f221e4b93f65f59299675336
```

```
24b9235750c30707550b58536d109a7131c5a5bbe4a5715567c12534aec76607
61eebb9fae2891c774589b80e566ad557ddef7367196b7227ea9870ef09ddfec
79d6b9319a6879b5205d76bf7aba5acf33afb59d17fc54e68383d6be5a08e9b6
6da53dcde008bb294b8582bd132cdcc49959fdb21e52721880c8ad0352c79f0
3a43bbd84c4cdfdc6c529005e1e7cd9a349a7168a35569ba5dea818968d5a914
66bd6e64e20bf62417198afc4e81c28dd77ed4028232398b52fbde86bc84f475
b9016710ce2aabc11a06b4dbac901ec16cf365ca3f2d53813948a693a0f93e79
c46ca5d5a6dca3d28ca50ad18bd13fca55059dd9b185f79f9c47196a4e81b210
4bc460a051e02f2e8444f` }
}
```

The following is the ML-DSA-87 public key corresponding to the private key in the previous section. The textual encoding [\[RFC7468\]](#) is followed by the so-called "pretty print"; the public keys are the same.

-----BEGIN PUBLIC KEY-----

MIIMKjALBg1ghkgBZQMEAxMDggohAJeSv0wvJDBaoL8zzwvX/Z153HXq0G5A1jP
p+kOyXEkpzsY05uiGrZNdnpDP1pSHv/hj4bkahiJUsRGfgSLcp5/xNEV5+SNOYlt
X+EZsQ3N3vYssweVQHS0IzblKDbeYdquH4036misgQb6vvhkHbmvYAhTcSD3B504
6pzA5ue3tMmlx0IcYPJEUboekz2xou4Wx5VZ8hs9G4MFhQqKkvuxPx9NW59InfnY
ffzrFi009Kf9xMuhdDzRyHu0ln2hbMh2S2Vp3471vcv/6aTgV0jm/fI1r55063dz
ti6Phfm1a1SJRUVYRPvYmAakrDab7S0LYQD2iKatXgpwmCbcREnPHiPFUG5kI2Hv
WjE3EvebxLMYaGHKhaS6sX5/LD0bijM6o6584WtEDWAY+eBNr1c1x/GpP60aWie2
eJW9JJqpFoXeIK8yyLfiaMf5aHfQyFABE1pPCo8bgmT6br5aNJ2K7K0aFimczy/Z
x7hbr0L006oSdrph7njtfl1y1tnzdRYqTVAM0aru6v1agojFv7J26g7UdQv0xZ/Hg
+QhV1cZ1CbIQJ13B5U7ES006fPmu8Ri0TYCRL0dRZqZ1HhFs6+SSKacGLAMTH3Gr
0ik/dvfvwyFbqXgAA35Y5HC9u7Q8GwQ56vecVNk7RkrJ7+n74VGHTPSqZMvuKMxM
D+d3X12HDxwC5bLjxQBMMv8kybd5y3U6J300cf1CXra8LKVs4SnbUfcHQPMeY5dr
UMcxLpeX14xbGsJKX6NHZJFuCoP1w7Z1zTC4Hj+hC5NETgc5dXHM6Yso2lHbkFa8
coxbCxB4vvTh7THmrG1/v70NxZ693LdrRTrTDMc2lpZ00nrFz7GMVCRFwAno6te
9qoSnLhYVye5NYooUB1x0nLz8dsxcUKG+bZAgB0vBgRddVkvwLfdR8c+2cdbEenX
xp98rfwygKkGLFJzxDvhw0+HRIhkzqe1yX1tMvWb1fJThGU7tcT6pFvqi41AKEPm
Rba5Jp4r2YjdrLazMo/7BgRQ998IAFPmlpslHodezsMs/FkoQNaatpp14Gs3nFNd
lSZrCC9PCckxYrM7DZ9zB6Tqq1IQRDf+1m+04+q71F1nslqBM/SWRotSuv/b+tk+
7xqYGLXkLscieIo9jTUp/Hd9K6VwgB364B7IgwKDFB+54DVXJ2Re4QRsP5Ffaugt
rU+2sDVqR1GP/INBVc00/m2vpsyKXM9TxzoISdjUT33PcnV0cOG337RHu070nRpx
j2Fxu84gCVDgzpJhBrFrO+hX1c5JcxvWZQqbDKly2hxfE21Egg6mODwI870EzyM4
54nFE/YYzFaUpvD04QRRHh7XxfI6Hr/YoNuEJFUYQBvtv2IoMbDGQ9HFUbbz96mN
KbhclEbaZfphXu4WSVvZBzdNIRW1PpHF2QAozz8ak5U6FT3100QITpzP9rc2aTkm
2u/rstd6pa1om5LzFoZmnfFtFXXMWPeiz7ct0aUekvglmTp0Aivn6etgVGVEVw1N
FJKPICFeeyIqxWtRrb7I2L22mD15p+0iG0S10VGMqX0LUZX1HtaiQ1DI10fh7epR
tEj6RRwVM6SeHPJDb0U2GiI4H3/F3WT1veeFSMCIErrA74jhq8+JAeL0CixaJ9e
FHyFRSyM6wLsWcydtjoDV2zur+mC0QI419oCNmMKU8Def0NaGYaXkvqzbnueY1dg
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```
5VvgYiIvi6kKl0BzMmsxISrs4KNKYA==  
-----END PUBLIC KEY-----
```

```

SEQUENCE {
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
  }
  BIT_STRING { '00' `9792bcec2f2430686a82fccf3c2f5ff665e771d7ab4
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927665689e94db961ebaec5615cbc1a7895c6851ac961432ff1118d4607d32ef
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3a4f3633fd434d787c170977b417df598e1d0dde506bb71d6f0bc17ec70e3b03
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```

```

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c1fc856d1802762840ebc72d7988bde75cbca70d319d32ce0cc0253bb2ad4557
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ee3206149a7d550d67fc5fdfe4a8a5c35d2510b664379ab8f72855a2af47abce
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4d093cc6716c2342eb1853d48c85c63ac8a2854462c7b77e7e3bd1eac5bca28f
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09ca947c39dfc82d98eb1caa4a9cbe885f786fa86e55be062222f8ba90a97407
3326b31212aece0a34a60` }
}

```

C.3. Example Certificates

The example certificates in this section have key usage bits set to `digitalSignature`, `keyCertSign`, and `cRLSign` to lessen the number of examples, i.e., brevity. Certificate Policies (CPs) [RFC3647] for production CAs should consider whether this combination is appropriate.

The following is a self-signed certificate for the ML-DSA-44 public key in the previous section. The textual encoding [RFC7468] is followed by the so-called "pretty print"; the certificates are the same.

-----BEGIN CERTIFICATE-----

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MzIxMFoXDTQwMDEyOTA0MzIxMFowIjENMAsGA1UEChMESUVURjERMA8GA1UEAxMI
TEFNUFMgV0cwggUyMAsGCWCGSAFlAwQDEQOCBSEA17K0clSq4NtF55MNSpjSyX2P
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C2U703ak4HamVZowJxhVXMY/dIWAq6uSXwI4YcqM0Pe62yhx9n1VMm10URNa1F9K
G6aRGPUyYKM07J0S7z+XcGbJrdXHEMxkexUU0hfZWMCBfD6Q/SDATmdLkEhuk3Cj
GgAdMvRz155JBnSefkd/oLdFCP1l8jeDErg8Jb04jKCw//dHi69CtxZn7arJfEax
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AAAAABcmOEM=
-----END CERTIFICATE-----
```

```

SEQUENCE {
  SEQUENCE {
    [0] {
      INTEGER { 2 }
    }
    INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
    }
  }
  SEQUENCE {
    SET {
      SEQUENCE {
        # organizationName
        OBJECT_IDENTIFIER { 2.5.4.10 }
        PrintableString { "IETF" }
      }
    }
    SET {
      SEQUENCE {
        # commonName
        OBJECT_IDENTIFIER { 2.5.4.3 }
        PrintableString { "LAMPS WG" }
      }
    }
  }
  SEQUENCE {
    UTCTime { "200203043210Z" }
    UTCTime { "400129043210Z" }
  }
  SEQUENCE {
    SET {
      SEQUENCE {
        # organizationName
        OBJECT_IDENTIFIER { 2.5.4.10 }
        PrintableString { "IETF" }
      }
    }
    SET {
      SEQUENCE {
        # commonName
        OBJECT_IDENTIFIER { 2.5.4.3 }
        PrintableString { "LAMPS WG" }
      }
    }
  }
  SEQUENCE {
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
    }
    BIT_STRING { `00` `d7b2b47254aae0db45e7930d4a98d2c97d8f139
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```

```

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4db9784cf05c830b3242c8312` }
}
[3] {
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    SEQUENCE {
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      BOOLEAN { TRUE }
      OCTET_STRING {
        BIT_STRING { b`1000011` }
      }
    }
    SEQUENCE {
      # basicConstraints
      OBJECT_IDENTIFIER { 2.5.29.19 }
      BOOLEAN { TRUE }
      OCTET_STRING {
        SEQUENCE {
          BOOLEAN { TRUE }
        }
      }
    }
  }
  SEQUENCE {
    # subjectKeyIdentifier
    OBJECT_IDENTIFIER { 2.5.29.14 }
  }
}

```

```
OCTET_STRING {
  OCTET_STRING { `329a07b1fabb48f52a309f11a1898f848e23
22ff` }
}
}
}
}
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
}
BIT_STRING { `00` `67a8951fc308e12f6867611fdc254bf4bcb514f7f5f
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cdb5a71947149dc7689dff24d6ba6b63e6cc23140e32934b6e9da765b4332011
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8b174eaa1f73121c9add500cecd8618b302bedad72b62f793bd0f70ba8c5e16c
```

The following is a self-signed certificate for the ML-DSA-65 public key in the previous section. The textual encoding [RFC7468] is followed by the so-called "pretty print"; the certificates are the same.

-----BEGIN CERTIFICATE-----

MIIVjTCCCIqgAwIBAgIUfZ/+byL9XMqSuk32/V4o0N44804wCwYJYIZIAWUDBAMS
MCIXDTALBgNVBAoTBELFVEYxETAPBgNVBAMTCEXBTBVTIFdHMB4XDTEwMDIwMzA0
MzIxMFoXDTQwMDEyOTA0MzIxMFowIjENMAsGA1UEChMESUVURjERMA8GA1UEAxMI
TEFNUFMgV0cwgggYMASGCGSAGSAFlAwQDEgOCB6EASGg9kZe0Mes93biwRzSC0riK
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```
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IA==
-----END CERTIFICATE-----
```

```

SEQUENCE {
  SEQUENCE {
    [0] {
      INTEGER { 2 }
    }
    INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
    }
    SEQUENCE {
      SET {
        SEQUENCE {
          # organizationName
          OBJECT_IDENTIFIER { 2.5.4.10 }
          PrintableString { "IETF" }
        }
      }
      SET {
        SEQUENCE {
          # commonName
          OBJECT_IDENTIFIER { 2.5.4.3 }
          PrintableString { "LAMPS WG" }
        }
      }
    }
    SEQUENCE {
      UTCTime { "200203043210Z" }
      UTCTime { "400129043210Z" }
    }
    SEQUENCE {
      SET {
        SEQUENCE {
          # organizationName
          OBJECT_IDENTIFIER { 2.5.4.10 }
          PrintableString { "IETF" }
        }
      }
      SET {
        SEQUENCE {
          # commonName
          OBJECT_IDENTIFIER { 2.5.4.3 }
          PrintableString { "LAMPS WG" }
        }
      }
    }
    SEQUENCE {
      SEQUENCE {
        OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
      }
      BIT_STRING { `00` `48683d91978e31eb3dddb8b0473482d2b88a5f6
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```

```

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f475b9016710ce2aabc11a06b4dbac901ec16cf365ca3f2d53813948a693a0f9
3e79c46ca5d5a6dca3d28ca50ad18bd13fca55059dd9b185f79f9c47196a4e81
b2104bc460a051e02f2e8444f` }
}
[3] {
    SEQUENCE {
        SEQUENCE {

```

```

    # keyUsage
    OBJECT_IDENTIFIER { 2.5.29.15 }
    BOOLEAN { TRUE }
    OCTET_STRING {
        BIT_STRING { b`1000011` }
    }
}
SEQUENCE {
    # basicConstraints
    OBJECT_IDENTIFIER { 2.5.29.19 }
    BOOLEAN { TRUE }
    OCTET_STRING {
        SEQUENCE {
            BOOLEAN { TRUE }
        }
    }
}
SEQUENCE {
    # subjectKeyIdentifier
    OBJECT_IDENTIFIER { 2.5.29.14 }
    OCTET_STRING {
        OCTET_STRING { `1b0563e3cd3346149c8c9ebcf23b0a4e5a90
0eea` }
    }
}
}
}
}
SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
}
    BIT_STRING { `00` `11816868a90c66934bdbb1d19c53a6a5dc30535ff6d
cc8669b24284ae9310e9a57c7918702b5fa49c633be475d5492d9d7eea391426
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```

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The following is a self-signed certificate for the ML-DSA-87 public key in the previous section. The textual encoding [RFC7468] is followed by the so-called "pretty print"; the certificates are the same.

-----BEGIN CERTIFICATE-----

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AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
-----END CERTIFICATE-----
```

```

SEQUENCE {
  SEQUENCE {
    [0] {
      INTEGER { 2 }
    }
    INTEGER { `159ffe6f22fd5cc42c524df6fd5e28d0de38f34e` }
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
    }
  }
  SEQUENCE {
    SET {
      SEQUENCE {
        # organizationName
        OBJECT_IDENTIFIER { 2.5.4.10 }
        PrintableString { "IETF" }
      }
    }
    SET {
      SEQUENCE {
        # commonName
        OBJECT_IDENTIFIER { 2.5.4.3 }
        PrintableString { "LAMPS WG" }
      }
    }
  }
  SEQUENCE {
    UTCTime { "200203043210Z" }
    UTCTime { "400129043210Z" }
  }
  SEQUENCE {
    SET {
      SEQUENCE {
        # organizationName
        OBJECT_IDENTIFIER { 2.5.4.10 }
        PrintableString { "IETF" }
      }
    }
    SET {
      SEQUENCE {
        # commonName
        OBJECT_IDENTIFIER { 2.5.4.3 }
        PrintableString { "LAMPS WG" }
      }
    }
  }
  SEQUENCE {
    SEQUENCE {
      OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
    }
    BIT_STRING { `00` `9792bcec2f2430686a82fccf3c2f5ff665e771d
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```

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```

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b3c009ca947c39dfc82d98eb1caa4a9cbe885f786fa86e55be062222f8ba90a9
74073326b31212aece0a34a60` }
}
[3] {
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    SEQUENCE {
      # keyUsage
      OBJECT_IDENTIFIER { 2.5.29.15 }
      BOOLEAN { TRUE }
      OCTET_STRING {
        BIT_STRING { b`1000011` }
      }
    }
    SEQUENCE {
      # basicConstraints
      OBJECT_IDENTIFIER { 2.5.29.19 }
      BOOLEAN { TRUE }
      OCTET_STRING {
        SEQUENCE {
          BOOLEAN { TRUE }
        }
      }
    }
  }
  SEQUENCE {
    # subjectKeyIdentifier
    OBJECT_IDENTIFIER { 2.5.29.14 }
    OCTET_STRING {
      OCTET_STRING { `89886750b57c24db3fc012e61ede59753337
374f` }
    }
  }
}
}
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
}
  BIT_STRING { `00` `08783d565efc7b97440f8bd9818b466be538dbccedb
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```

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4e2da95f19a508d01dc8f846b1652d4de57a7251e6393240ed14303e395fb188
079345e0fb853f876cc1edb4290e2684cc35311e8602c71a57bd3a6c9a804591
727be34f6fab723f48a196febcb6f0f9b34f344fd9706790a3e63d1a989cbcbdf
30f8eb71fcb024635adec568fe9d39a194c8cd2fbbf6a131390dc311e9c5381b
5542466b3c60a8eeb621e6e653b8b52fd5dd3f8d0f3fe3f0ea948b0c7862de25
e064c2947359fa25bd58a35e5ce33677646d0874150b72522ec6241d19d06db0
380cd0ea8be776e7cf7ca0d1bd59c5584fece0db84d1a767a162029d682e4063
7d7c378c847ae185e2d6dffe4e15d55bafd0d35fc8d7ff56fe5fa7cbc2ee1833
7184dc62f5e50dec5cda90629d6c81a9fedab2579019cd49dd76bf997f543bc2
35941a70107925ff095153ec610772c5fd524c80c228d80e781e864e295d20c6
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453807b26361b1eca6fcec4e06c504166742c12f8a44a359fef2727d34f47201
f75a7055629b28397e575e4cc9de39adc08f42410b5232f8f2e7b86fdf3e1ebb
e734b7acba49d308a6151c1352de2e20b1fed060d5e6fb58d6f23b2847dc53b6
7519b92dba604e448f3990570f09bd65f685545a02462cd24c72f2f7989cbe87
b0c52da52eea1770aaecf7d568d0b1bf1aed3ca8f58f332299e391b4413b6c6f
eba11d43262177a2a446ce5afc59c48288781cf9167fe5a1bf42629c6d094c65
37abdea5af4b4a3a7f1e8a3e8cfff1026ddefc29bae39e75249364a953ec52231
bb5813a80b3af25efca43800a74c4664632f6dc189cc2cd95478b594fc578ea3
a15840e92822b7166c8611d464af2e8d1baa5bcaf1c1649589a7eb16b889b54e
0b7ced0ba25a51e34f4d0f152f6e9e1f43682d81a5de05f89628b1b5ef10032
7e4b4fb3a02385762b4ab1e721da7ff61733c41d7071e819ec44c03311474330
e97a6c0248d1dd99419feb83980f2422a9e7c9065469c4103d76bdb7b8524c4e
21914095fe25eea171d88dce27d96f7649a717d9415ba05138b6a26a685fb768
f75564884fa38cc9bade16b94db62d1f9da3ce294f3e917301855676a7ee7b3f
77bd07c7fb8b53de30082bbacdf34f19e1db5aaff7a3188ef408c6a9c906b42b4
1193003d273a5a69b0ca5844bbbcb8c7812330aa3f93e155b8681f9edfba2ddb
b011cae933e72b34d1117d26d665b195322dca63429bde4183c02255ccf0c595
873d25c4c73db307d3165e2c0be0a0616c8785a4e83d581ec3eb0f59ed7a3832
3d9772fdf36818aed3b485c38203fb1b019f0e0ada9099543291f106f6d2d057
8c53734d101938945284ce689a35b3ff93fe2d40e07e31310e55d21c09cbd0db
44a64ea3f16ed2ddc243ef5d6e5ceb4b0a81dc0564ab21e9d81cbc16c5683bad
d91125d8b4d551f3091be2115ea121b21438033786c5b76bfc8c0e0721d0fbd7
090541d3bdb8e99cb029a135e2ed1f6c490572e625ebce83c7fa02df21d16b0f
b93db803cf65ebfb1380b1ba584717b6cb65fe6236adb3613d4a2b0443254dec
83c9679ad84e2609cd475f2d9cb98a06fdfdcc73a88be0fac78c6a42e351b698
bdc31172568deaec20964d5bc529612d580ba0a7bbcb425bffe1bf3ef1a40eb7
504d046ba213e00a0714d11950e94b0e249e3ee6e0b6cddb4ea32b4024011a68e
51160a133b25f99034273255916a92ea3a94fb2bcfafcc0a2e9e9dc2f8c3195d
d0ee7c704b8bcd5d8960f2bd2160f7fd304c107d27b3b0984f50deb813a467b0
73e6347149a1cf4b5332289d635d5d23c2730b30368a5ce3cceb6155347f0df
21f611044505bce3806bd8edba86324637c6a9210830b636602a83527b41eee6
0f2d2df4c7c6a571ee8514848a47beb0a7203f8e4b91e4fa67ea3022fe9d9f94
14884016e66fe48536167e12f0dc550e801004c11a86c5b798e26ca9b1f25841
624ad2327137908dd23ba5f65eeb107b8bf1e4f45218e44f15e75dae8df9e78b
edf5e65cb12278f1524d4597c037d40aa1222ad514046393d5f7e29759e61087
bf1f1d3907d2d2b6f21bb8a1a7098c533a897cbcb8891b56a1bc65ab8625bab6
6f36e2afc6eb084cdb2159be5437e5c437a738ef80ada9eb1d08b173d22a3a6e
4eae6b29b329a93c2dc6b47993606e7ecff40431831e83aa7c64a09e7eb291b1

```

a9f671c14ff8517251b0419b517095b97fd7010ac59063be3652d27414262ecd
c2f9b91a8a46fa583bb4588365c4942dd8243268fc9f5fa3343cbe17fc3539d2
4341d582e0a463539412e793507e4be487ebf9cc7e26476bf5e68eec99e6280f
eeaecf057f2d36000890dab50bb7f859b209857d67830e06a66b535ca763bac9
79b9eed31e2b9b3095ab64ab961c57f6a6660cb172aedeb3d85bc9bf3b9fa8fc
4673de2813d138ef85e0d456e501e59dbade75add36acf197baf472f6351f23e
780214dbc6947aabb673e033d61aa61f9a87285f8afbc5bf879c91bea9692fa9
33f7010116f028b32de397100350f5808e1761a61f08361a2dc8c3cf0aaf111
cf44fdfd1088e428866be3a58b5f638c5c762fb2790ade914be0cf612b6b3bde
c6b88accf6d1b3d78c410c05ae5117ca1025d32cc03a016f330236018d6579cd
0b9930b317a2ecaa2b41491b826a7d259226ff83bc3bc67660a4c5c0620f33ba
c03196a4517ae45f33ef01ca53b54ccc96b72d68e57ce9489fb7dea6fb8dc88f
8f2bd532bd7d1a9bb476f5bc4dc824cd24742e549bfddd6ae89095fb20739a65
7c98ed3e1b323cb0d3232c58e6a7cc3ca1d32ece1a10e05e2252e36cb65d4d14
1ff24618465b6651297cd34d38f61c62f31fb8e970c30653225eed4ad93a9340
2d67beed1e6c368aee7bdf4ca85e54eb2b17bbda501d0d096f5cb4e47575f0fa
8c60f8ed3bf2766de6374342014c5d8c72a9a9d981ce6c7069f75f843fb97819
d104a584f12b1a3b480b9fd774052b698259368ea5bb7af675809421fa3ac6e9
feebe427a13ece5e96fe85cd382b2e10607ab911877ad07e74a200621d3cc2d9
02dca836e92b8ae754b483a8a91b80a0b0c113c48b0f1253c599bb9cf01bdca0
5112c6378a1b2de49053c507c82b5e11b6e91abb2d5e9000000000000000000
0000000000000000000000000000000000000000000000000000000000000000
}

```

C.4. Example Inconsistent Seed and Expanded Private Keys

WARNING: These private keys are purposely bad; do not use them in production systems.

The following examples demonstrate inconsistent seed and expanded private keys.

Three `ML-DSA-44-PrivateKey` examples of inconsistent seed and expanded private keys follow:

1. The first `ML-DSA-PrivateKey` example includes the both `CHOICE`, i.e., both `seed` and `expandedKey` are included. The seed and expanded values can be checked for inconsistencies.
2. The second `ML-DSA-PrivateKey` example includes only `expandedKey`. The public key fails to match the `tr` hash value in the private key.
3. The third `ML-DSA-PrivateKey` example also includes only `expandedKey`. The private `s_1` and `s_2` vectors imply a `t` vector whose private low bits do not match the `t_0` vector portion of the private key (its high bits `t_1` are the primary content of the public key).

The second and third examples would not be detected by implementations that do not regenerate the public key from the private key, or neglect to then check consistency of `tr` or `t_0`.

The following is the first example:

-----BEGIN PRIVATE KEY-----

MIIPKpIBADALBg1ghkgBZQMEAxEEggoqMIIKJgQgAAECAwQFBgcICQoLDA00DxAR
EhMUFRRYXGBkaGxwdHh8EggoAUQyb/R3XN090iucd1YKBEGqTQS7Y+jv/dLu0Zh7L
GSHTP1/J04jvDmqbhRvs7BmZm+gQaMhZ1t8RXGCMFQEXDrbAVcIvY1WSSXbYlaX1
TSw4WWxAPM72+XPiK1+MfCuoNjNEcJCniyK7Qc/e2vvLLt7PkHDM5hLkKrCh8T65
3DwUkDGJwoHgsDHa1ISCEgijTDDSKEoEByDDRELgQC5EoHEBqSwDjMQSQSQYMiQA
Ii5K1mALGZAiMyBShkUbCEyTGIQZAG1TgAwQpChQBgogBgwJETLSxEDSEgIENIYj
lQygtkxbSJGMEoQgGQKRGIEKJRACoG1gkCgDxjCTBJARuJAERTLBIEzawpDZiCwY
RiTksAUjsWYKEIwEgXDLpDDYRmLBxhDIyEXBlgwEEgrkKGYcJXCcsOhigGxi0EWE
gEyjoA0jBw7IRiAk1SkkRgVICHATIUXghCGQsg3QNoAZgE0blmEUEIUaJkCcwIij
GBADAiGSM1GYCDiI0YpAEm4MJkEYGU4iAmTCMBFCFhJjFiwRo4TigCXSrmKakgAR
uA2LhgBRlnHIRiQIiUEDFUCHIm4kNwMAJC7CiIUEMYxawILCRI1YxgCZMpIbISDL
Am4YGYDYxiRBNnIZkGVYOG4IIAwCFcpjFoUBtCVQwmGJGVAisk3DGCokGCKbRmgQ
NUIgNmLbNAWLsmxIEIoByI0hMA6MFCZCJAQLN4xDBi1CSiBYGIXIpAQUtjHRNgwi
gykAok1cuA1kiEXIAEGU0ExiomjUBi7ZAg3MthFh0GTIMpJRyElSgAHgwDEAIgrB
RGaAtIRQCDASxiikCGBKsGHKxkESyGhSsHGbAAwIR2ZhGGxRFImBRoYJOUSDAjeK
kWhh1IFZrKGiBjLaBnCZMCzIji3akpDBACDAsGWCJDKDRIVcxGwAQyKJxhCjBABh
hCSjQBJRIA0YMoBBNirIsCkgRwgaEkTdpEiKYzYmmbD1hBiJnIbRWXDpmXZwGAU
EAjQxG1JMoXQBg0RJEZjtAABqUuAM4BCMGBKgEmCNCBDGAgSBiaSRILKMAHhNo5b
IiikBwZUEi1LoEGYRgpMFEoKNiQgI07AFgUDRIyAtkEUkzHLJgARmG0KEg7YEGKQ
NgwUAXGJBirIJmZSBFhkBkDckiHIEHFkGC7kuABSkGiLqChLJEKRJoGZiJFUNG0K
mIG8aRx5dr9/gBkPfhWZrwn4DSmTPR/Vn01JddemytttdtkeLCZ4DW7+GKb7Z8S4f
HY7JlsvtetEEMyRAS8/INLBzTBrGWIRQqWxf3YcrxGG51ND01vdrYH7wnyS0ku6m
N12BMMwLEfKkm0SU747o81iHE+wiM2bPH+rG7eP6rIrB7NRY67odfeBGboLHeSdf
79U3GOWczZiFB5wtZGzNoVpiExABNAydQC40JIPvpXR0ULrErVz9y33/zj9KIZJy
+saqdCSsuX3kbavVhZQz7eytus2Aji7uSWgPb4M7FqBoFcpobHX/jVvHD8oaBt2
TOjtuObFujQUndcztr62etukrM+iwyyLR4WCpFev9qGM+ZP9TCsLbEDu/rVMVS81
dnKlkkYhy/pUgsGU2jg1bTD83Wib8laAlKZgXsQLbsyP2hpmU66+mX/2gQR9rCzh
jSFDfiIGPo1nU2yelQMj8Y0niHNv8I5ZRKylmRFpDZo+QPVoXMnwTg0eF/c3UC0
PTc59SF1UpXMSPTtjYLHENPlqJnHLb/PZMWlqfd+FE+i4GfHfKDH6RF3NUjPY0Jx
I1EJ51/HxG+zK4c1abd6LU4fMGnnKrNK1NSF5yoq8b68GIspz/Mnni3Z8++arXx/
hzMVayoTe6vtL0ZtyByyV26jjrxOEMpf0ZLzjKWB+Q9a+Z6QxEcTtpVls0hnxB9w
cWFz1hzd0z1ZaMv89k3iYgajdmNIHeUQdz8wwc1621onspo5Y1zuruFSorrzz/Ru
yyg3iHNFmRv2SCNuWcziaFTSd8HBtInzNWmeqBeF7HW1hsCpRoR02ZV4iM+REFrj
qPVHh3zqURGGSdu1y29uK6M2vjUp0w8NfyuvzbHIy2hJz3Py9kiZotff4k0gU25D
11b+/IcaVavqBxCUAz9N4c29aBGZ08reC+X9kPWuNE8NY7e3j4YmPcWppZGfXnY9
PNV0pLyhLeifev2Wk1ahcLVYLE61/cFE6qxmThkD8uTrZ7h75JmUqDmKNVjtJW5N
YS5XSZQz4bFhsdXvpED5F5jwr2NUPpZDZdkjuEKXu811114F4wx98g776d6LI/zTY
a06arDBhDhmeyDQZFhMtl575XeFZGdP11IVo4UPSCQKzc/AMx1rjNrQw2wNZJ+t
6JDEJq75MS7q5C7gvPpBd3qdmBnQwLFvyCj8ohXcpqc1Lgw12BFntm5L2JXX1e/7
QmhVrMEkSwJznkd+b0qky9uPbI1Nr1fw0+NJBqCJtxVvjngV3rE97E1RqzHFxaH
QQvju+iK/j03mKXQes6be6UWIrYz8+RhZ4jw1K2nPDklHM0+0p2sN1ha3BY1+Fob
uXxZug5ze+Lor7aiIiy18xn64MxZ4QBP3pFpKeW3YJKoLcJSexuJlKJ8Ky5WjnJ+
skZeuWRgmW/0YyRcKyyy1rgnWv0A2oyBqe8ujjv5MD20i10q/mxtA+a8IAQ0oq0L
F00uc91QcXXoUdXnQ+ZCCeNIUg1shMyx+2v6smyMLuSFEQ3R17Br1Sgw6lu2gD0S
XMYOX6h8w0Ww9ml1Huth5xm21mYiPLiejT3vP0yWrJNQ7pg41/0VGBTG+1zaN5fo
paZzqkJijn+EH7d+G8RVLGHu0gkbp1rNqDAIHAiCn076b3CuBam2ngtjQzBPULSU
AqXPTG17rJg2B+fzgPKAgh8vuZLEaXP7/XeNMwNe6QsNuU9gfln7Tt+pqYpwm1gH
Wkqor1xYXy+1md2Ct3tLbznuPLFIQ3NVBkeDW+NVvpPvC+CF/NefkSuz0aBP1Ta
itxMHENeGFxR5cf0Sp43j59iGkdWBtJBCV8uWf4qRgRG8fdbfQ+11qAJEx4v8r4H
2Hsm6eS/CeZ1Epe9fnobwS1BBNoczKSL+noqpxcmgAjbcEtZtsBXSJVBSj40Cdt3
fA/6IfpWRsNBIVR1aD2p/a0U/RH3FCZKdhwF2ZhBLEHEWWQ0Cr1v0W68/r11FuIW
Ycyq0oJDEup7oFhc0k4aUwdv50HJAWk3ehaPvBP+z1z84DmyVMQjXYJl9gZShi+9
tFV4KJ8aZz/kCdufmWwtLJKHIBuVx/hqbY08Xg4XyWv2pZpZIGeW779l8wQE1MI
2Yt6grThI3sytb+dM3JvqUW79clVJ288BqRZMJSN02vUIo4vPqyM/Wcuy465qS0V

```
ns+zr0zC2uo3z3LqK57arYABNRm8CV2Vxa0qH61GvYyUrA==  
-----END PRIVATE KEY-----
```

The following is the second example:

-----BEGIN PRIVATE KEY-----

MIIKGAIBADALBg1ghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0s19jx0X
0Xidr6FwJLMW6b7J0c4Pf3f421ZE3No2a/5HNL2V9DX/mmE6pUqkHCxpTAQzmgeX
+rtI9SownxGhiY+EjiMi/+Yj7IENs77jNoWFSogmnaMg1RIL/P6JoY4w9xFNg6pA
SmRrbJlziYYNE1Iu4ABuI4SBkYZhmyYNEYZk1KYoiHhEgkAomBRhSKZhTEJIoZII
wjgpUSRICKElwggxCMRxIBQJFINSgKeAhBBuyCBwIrVvKCLBhDAcEmBJEUyhpWQBG
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TBL08CFkqhREqFk
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYSUmGJMMWEGpZtSpqsmQZtpEQyIKdkWjJu
EbVwIJJhJB00BIUsCkhyyKBR0wgqmqSCAWCQgJAd0WRSIEKrkYMBt4LKNgXkKJIDQi
wCRBUNCxCIegYaIBUiJSG4CAmJQAE5NN0zIpIhcKmJJPgHRRICchnMagYqKBSBhp
GoVNg0RpWyBBAXJCyxhGAakNDAXg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy
UjJyVKZAWHgQDDISksKAUhJiXIIoC7RsA0KNUxAMFAE04TZSiIQkkQIKY0YmIAYp
EcIo0CBIArNsojYJWoZiY7Rhi0ZixECCGokJEAJNjLJFIBILJMKFiCiMycBNWUgi
CiduwTRkTJBgW0RQgoZJQ4gEQ7KMYDCAoogthKRtjKYp0MaEQgZGiYhRAKmAUMN
5DgNpAaN05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdLJChiFCiQCRBh2UAiGzNg
CQKS0CSBIAQISRhEoyItXIhEFJgIpEZhAZVkcZkKDJRQyKbQ0rIgwDgBgjCOE7kI
kYCEFipwBiRejUNoCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp
GiKJFEUR3IJEUJZFDESEwLIEmqYFQ4YSRDJuiEQhIKhMmjBw47gtYyaIAyVJA00M
SKgJyhRyUzR0EkMIG6cEWTAi2ZSA4jQigUISnDAqLDQmYQRFJCYoE0YJSjJtESgJ
GLglYigRE0ENQbIRKIRMIxISosaIycAwIgyG0hi0hIYwKERSEogx2SBxE8UoQwY0
AzBgZKaEWCZSTIGBHvclYshf+k0s+kkhfysXLXu8FGIObZgKcaq73wxF6aIG7LFC
P+4V3swXYBMAFJ2SI81ubG4fQ0Qfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrhMhVI8
qP5srSlK340+FbEI/3IdDMh7w906dZAYSW6EVm0pH8nhw8U6YdhnQgsE8JI1V108
ZaBjaP1BKV/QmSQLG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWM1795EeB6ptCTjy
7iuzwajFldY16ENC/eoB3CSyEa0vwoHPd+WREMerxUvwyG1IC5vidkcdydYDzumM
/as+n8+3A3k1YfSepEUpp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFeyZnp0Y+
SSKM0j2KHzeFbxQt7kNsJ+Cr4kljG0quAR6gMA2yTV+ogRvjcyY1TwxSlfNCu0F9
PP6wsf0zYiwp4Uy72S4TY8ZevUUEt1EjKblnDjLhssZ6V0fxpV+Ln56gToyjpwXm
KjxeY3N0r7eutt3qYSzeKPAaIC16pONHITJ90/m4mJTQGF1dTXEZ7+Ny07oQTLi7
CYHgdN46/iANqq6tgmgEXyRNv0Ma+rNO+994JHTS/VcRj2RiFJNO2Zy60wA+jWej
g29vGfxBkQzlfj7jrpnrhNUU63YeY2h0pW+XkdLdSxuxYWi5SMgX91oiKss0jNwD
zEr+j2cVfho203+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTewZz3N0/xfNLhV3MbH
eIVknp5x9D1K6g9Lcsp+2gV4uhPTGmWNLQYKmmB/ae0b5516L7HScj04+b+r4Y+0
ezzakG50m16ULI6uspYHDr/TZJR61AzJeL7Wazd0nm1dzXvoxJREDiuEzs/vuYwL
7fs8QeM1nSzXGX++cgxIqmXrZGXB7mPjVpwq3HREkTcLf3gm/gt3odGdZBAduYR
gQa0LS73N0f1YB/kuLDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD
AZxvXCfLmNomFEtkIlp8kysw92Hnii1Zodi4PsY0Si9t1H52VwbQC/SnmmqSbDup
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U51h1kKjM+n1k9bj9TU51CCOnmozKF
HX91JSKpKLkX4n4tbUITff4uv6b7HGeybAJUOaF9+vb4xWmjgotp2noqfQtPmA
fHEZCSaywAetg+rU5P0e2HLM0ZciAdKwJ/NUwSLTDNeLwddA/sy8b8KgRGxuM0rF
H1ppCYqi1EfyCFt0TkuSZmJpIdLeR4UYzQkM4meuotJ621f9iLSXbYn7hDzc0mn
bKJnnmgBv6f7AxIW+1BilwS5kj2u13ThTERICrfsRmV5ZtZA0z2ftA6uBOGdkjQ
JYKAh+1Jqa/Ra5XXLZmx7coleqWTL/t6Bwmu1anA/wX7Dyu/KECe7XtfWAG+1kzt
AZ4ct4Ud0FHxApBnThn/sAizAcSs9KgiuxQhbb1pyr9Ste8idJaw8weZqFXRF/rT
dEpvozUD6nmLUt3X71QmYJ2/zT8ME7Fk1sBR9+1KEZcZpxLjinMoQCCB/xNUTVTS
wjev7TsVHEuo6fS964SZowZuJrvGnorwid7HFzHR3Fkeqxfvc3RzTA/kdU1Mg4Nr
3TSg05vImRRxYGG/uY7G5hw+1E003K81JDxkcIa56nAYsNmoolAM7LAKveJJjWnC
M2EBp3LL5PVxUj9RvQWILN81i4ScwUCqH68iQjoShRzg4z/UiXWk1Z+1xf5BjJ0Q
gZGrbnQbd7/gLL1pjueVxGbWFWGeZEE4LG6sAYN06atzzqgLviNceNqRvXm2+C+J
l4XWhwDTk+Z1wiJNa3oa0hMgSVZ5ra7XAWe1CGZx01MQnbe299gTB0zf2Dsxxm7y
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKhqhjeGHKokyh4uax+GsW9pJl7cgZP
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxnHAPC5FzuZBPs
vnUn6HPkVcTmEKYY0arMC9VtJIPnjymLZqR46y9VjLr8qGvoR7rrAsWyFsJNiP6k
3ySbCeZwogcDq6wksKkavEpWRmAUQroQvs/TCZOIAFHQf1agWpN556jmvv7j8i+q
EGOY93BgBuQum+HvidJcJy8RqVCVxYfXE3MihN6dvTxyF7BonihY6w/2lmg=

-----END PRIVATE KEY-----

The following is the third example:

-----BEGIN PRIVATE KEY-----

MIIKGAIBADALBg1ghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0s19jx0X
0Xidr6FwJLMW6b7J0c4Pf3f421ZE3No2a/5HNL2V9DX/mmE6pUqkHCxpTAQymgex
+rtI9SownxGhiY+EjiMi/+Yj7IENs77jNoWFSogmnaMg1RIL/P6JoY4w9xFNg6pA
SmRrbJlziYYNElIu4ABuI4SBkYZhmyYNEYZk1KYoiHhEgkAomBRhSKZhTEJIoZII
wjgpUSRICKElwggxCMRxIBQJFINSgKeAhBBuyCBwIrVvKCLBhDAcEmBJEUYhpWQBG
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TbL08CFkqhREqFk
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYSUmGJMMWEGpZtSpqsmQZtpEQyIKdkWjJu
EbVwIJJhJB00BIUsCkhyyKBR0wggmSCAWCQgJAd0WRSIEKrkYMBt4LKNGxkJIDQi
wCRBUNCxCIegYaIBUiJSG4CAmJQAE5NN0zIpIhcKmJJPgHRRICchnMagYqKBSBhp
GoVNg0RpWyBBAXJCyxhGAakNDaiXg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy
UjJyVKZAWHgQDDISksKAUhJiXIIoC7RsA0KNUxAMFAE04TZSiIQkkQIKY0YmIAYp
EcIo0CBIArNsojYJWoZiY7Rhi0ZixECCGokJEAJNJLJFIBILJMKFiCiMycBNWUgi
CiduwTRkTJBgW0RQgoZJQ4gEQ7KMYDCAoogthKRtjKYp0MaEQgZGiYhRAkMNAUmN
5DgNpAaN05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdLJChiFCiQCRBh2UaIGzNg
CQKS0CSBIAQISRhEoyItXIhEFJgIpEZhAZVkcZkKDJRQyKbQ0rIgwDgBgjCOE7kI
kYCEFipwBiRejUNoCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp
GiKJFEUR3IJEUJZFDESEwLIEmqYFQ4YSRDJuiEQhIKhMmjBw47gtYyaIAyVJA00M
SKgJyhRyUzR0EkMIG6cEWTAi2ZSA4jQigUISnDAqLDQmYQRfJCYoE0YJSjJtESgJ
GLglYigRE0ENQbIRKIRMixISosaIycAwIgyG0hi0hIYwKERSEogx2SBxE8UoQwY0
AzBgZKaEWCZSTIGBH/clYshf+k0s+kkhfysXLXu8FGIObZgKcaq73wxF6aIG7LFC
P+4V3swXYBMAFJ2SI81ubG4fQ0Qfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrhMhVI8
qP5srSlK340+FbEI/3IdDMh7w906dZAYSW6EVm0pH8nhw8U6YdhnQgsE8JI1V108
ZaBjaP1BKV/QmSQLG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWM1795EeB6ptCTjy
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/as+n8+3A3k1YfSepEUpp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFeyzNp0Y+
SSKM0j2KHzeFbxQt7kNsJ+Cr4kljG0quAR6gMA2yTV+ogRvjcyY1TwxSlfNCu0F9
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KjxeY3N0r7eutt3qYSzeKPAaIC16pONHITJ90/m4mJTQGF1dTXEZ7+Ny07oQTLi7
CYHgdN46/iANqq6tgmzEXyRNv0Ma+rNO+994JHTS/VcRj2RiFJNO2Zy60wA+jWej
g29vGfxBkQzlfj7jrpnrhNUU63YeY2h0pW+XkdLdSxXuYWi5SMgX91oiKss0jNwD
zEr+j2cVfho203+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTewZz3N0/xfNLhV3MbH
eIVknp5x9D1K6g9Lcsp+2gV4uhPTGmWNLQYKmmB/ae0b5516L7HScj04+b+r4Y+0
ezzakG50m16ULI6uspYHDr/TZJR61AzJeL7Wazd0nm1dzXvoxJREDiuEzs/vuYwL
7fs8QeM1nSzXGX++cgxIqmXrZGXB7mPjVpwq3HREkTcLf3gm/gt3odGdZBAduR
gQa0LS73N0f1YB/kuLDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD
AZxvXCfLmNomFEtkIlp8kysw92Hnii1Zodi4PsY0Si9t1H52VwbQC/SnmmqSbDup
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U5lhlkKjM+n1k9bj9TU51CCOnmozKF
HX91JSKpKLkX4n4tbUITff4uv6b7HGeybAJUOaF9+vb4xWmjgotp2noqfQtPmAA
fHEZCSaywAetg+rU5P0e2HLM0ZciAdKwJ/NUwSLTDNeLwddA/sy8b8KgRGxuM0rF
H1ppCYqi1EfyCFt0TkuSZmJpIdLeR4UYzQkM4meuotJ62lf9iLSXbYn7hDzc0mn
bKJnnmgBv6f7AxIW+1BilwS5kj2u13ThTERICrfsRmV5ZtZA0z2ftA6uBOGdkjQ
JYKAh+1Jqa/Ra5XXLZmx7coleqTL/t6Bwmu1anA/wX7Dyu/KECe7XtfWAG+lkzt
AZ4ct4Ud0FHxApBnThn/sAizAcSs9KgiuxQhbb1pyr9Ste8idJaw8weZqFXRF/rT
dEpvozUD6nmLUt3X71QmYJ2/zT8ME7Fk1sBR9+1KEZcZpxLjinMoQCCB/xNUTVTS
wjev7TsVHEuo6fS964SZowZuJrvGnorwid7HFzHR3Fkeqxfvc3RzTA/kdU1Mg4Nr
3TSg05vImRRxYGG/uY7G5hw+1E003K81JDxkcIa56nAYsNmoolAM7LAKveJJjWnC
M2EBp3LL5PVxUj9RvQWILN81i4ScwUCqH68iQjoShRzg4z/UiXWk1Z+1xf5BjJ0Q
gZGrbnQbd7/gLL1pjueVxGbWFWGeZEE4LG6sAYN06atzzqgLviNceNqRvXm2+C+J
l4XWhwDTk+Z1wiJNa3oa0hMgSVZ5ra7XAWe1CGZx01MQnbe299gTB0zf2Dsxxm7y
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKhqhjeGHKokyh4uax+GsW9pJl7cgZP
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxNhAPC5FzuZBPs
vnUn6HPkVcTmEKYY0arMC9VtJIPnjymLZqR46y9VjLr8qGvoR7rrAsWyFsJNiP6k
3ySbCeZwogcDq6wksKkavEpWRmAUQroQvs/TCZOIAFHQf1agWpN556jmvv7j8i+q
EGOY93BgBuQum+HvidJcJy8RqVCVxYfXE3MihN6dvTxyF7BonihY6w/2lmg=

-----END PRIVATE KEY-----

Appendix D. Pre-Hashing (External μ -ML-DSA)

Some applications require pre-hashing that ease operational requirements around large or inconsistently-sized payloads. When signing with pre-hashing, the signature generation process can be separated into a pre-hash step requiring only the message and other public information, and a core signature step that uses the public key.

In the context of ML-DSA, pre-hashing can be performed with the HashML-DSA algorithm defined in Section 5.4 of [FIPS204]. ML-DSA itself supports an External μ pre-hashing mode, which externalizes the message pre-hashing originally performed inside the signing operation. This mode is also laid out in [FIPS204-ExternalMuFAQ]. This document specifies only the use of ML-DSA's External μ mode, and not HashML-DSA, in PKIX for reasons laid out in Section 8.3.

Implementations of ML-DSA using the External μ pre-hashing mode requires the following algorithms, which are modified versions of the algorithms presented in [FIPS204]. The nomenclature used here has been modified from the NIST FAQ [FIPS204-ExternalMuFAQ] for clarity.

Pre-hash operation:

```
Compute $\mu$ (pk, M, ctx):  
  
  # Referred to as 'External $\mu$ -ML-DSA.Prehash(pk, M, ctx)'  
  # in the FIPS 204 FAQ.  
  # M is the message, a bit-string  
  #  $\mu$  and ctx are byte-strings.  
  # ctx is the context string, which defaults to the empty string.  
  
   $\mu$  = H(BytesToBits(H(pk, 64) || IntegerToBytes(0, 1) ||  
    IntegerToBytes(|ctx|, 1) || ctx) || M, 64)  
  # The functions `BytesToBits` and `IntegerToBytes` are defined  
  # in FIPS 204.  
  return  $\mu$ 
```

Figure 1: Compute μ Prehash Operation

Sign operations:

```

Sign $\mu$ (sk,  $\mu$ ):
    # Referred to as 'External $\mu$ -ML-DSA.Sign(sk,  $\mu$ )'
    # in the FIPS 204 FAQ.

    if | $\mu$ | != 64 then
        return error # return an error indication if the input  $\mu$  is not
                     # 64 bytes.
    end if

    rnd = rand(32) # for the optional deterministic variant,
                  # set rnd to all zeroes
    if rnd = NULL then
        return error # return an error indication if random bit
                     # generation failed
    end if

    sigma = Sign $\mu$ _internal(sk,  $\mu$ , rnd, isExternal $\mu$ =true)
    return sigma

ML-DSA.Sign $\mu$ _internal(sk, M', rnd, isExternal $\mu$ =false):
    #  $\mu$  can be passed as an argument instead of M'
    # defaulting is External $\mu$  to false means that
    # this modified version of Sign_internal can be used
    # in place of the original without interfering with
    # the functioning of pure ML-DSA mode.
    # ... identical to FIPS 204 Algorithm 7, but with Line 6 replaced
    # with
    6: if (isExternal $\mu$ ):
         $\mu$  = M'
    else:
         $\mu$  = H(BytesToBits(tr) || M', 64)

```

Figure 2: The Operations for Signing μ

There is no need to specify an External μ Verify() routine because this is identical to the original ML-DSA.Verify(). This makes External μ mode simply an internal optimization of the signer, and allows an ML-DSA key to sometimes be used with the "one-shot" Sign() API and to sometimes be used with the External μ API without any interoperability concerns.

The External μ mode requires the Compute μ routine to have access to the hash of the signer's public key, which may not be available in some architectures, or require fetching it. That may allow for mismatches between tr and sk. At worst, this will produce a signature that will fail to verify under the intended public key since a compliant Verify() routine will independently compute tr from the public key. This is not believed to be a security concern since μ is never used as-is within ML-DSA.Sign_internal() (Algorithm 7 in [FIPS204]). Rather, it is hashed with values unknown to an attacker on lines 7 and 15. Thus, a signing oracle exposing Sign μ () does not leak any bits of the secret key. The External μ mode also requires SHAKE256 to be available to the Compute μ routine.

Acknowledgments

The authors wish to thank the following people for their contributions to this document: Corey Bonnell, Dierdre Connolly, Viktor Dukhovni, Russ Housley, Alicja Kario, Mike Ounsworth, and Daniel Van Geest.

In addition, we would like to thank those who contributed to the private key format discussion: Tony Arcieri, Bob Beck, Dmitry Belyavskiy, David Benjamin, Daniel Bernstein, Uri Blumenthal, Theo Buehler, Stephen Farrell, Jean-Pierre Fiset, Scott Fluhrer, Alex Gaynor, John Gray, Peter Gutmann, David Hook, Tim Hudson, Paul Kehrer, John Kemp, Watson Ladd, Adam Langley, John Mattsson, Damien Miller, Robert Relyea, Michael Richardson, Markku-Juhani O. Saarinen, Rich Salz, Roland Shoemaker, Sophie Schmieg, Simo Sorce, Michael St. Johns, Falko Strenzke, Filippo Valsorda, Loganaden Velvindron, Carl Wallace, and Wei-Jun Wang.

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