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

Digital signatures are used within X.509 certificates, 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 certificate revocation lists. The conventions for the associated signatures, subject public keys, and private key are also described.

## About This Document

This note is to be removed before publishing as an RFC.

The latest revision of this draft can be found at <https://lamps-wg.github.io/dilithium-certificates/#go.draft-ietf-lamps-dilithium-certificates.html>. Status information for this document may be found at <https://datatracker.ietf.org/doc/draft-ietf-lamps-dilithium-certificates/>.

Discussion of this document takes place on the Limited Additional Mechanisms for PKIX and SMIME (lamps) Working Group mailing list (<mailto:spasm@ietf.org>), which is archived at <https://mailarchive.ietf.org/arch/browse/spasm/>. Subscribe at <https://www.ietf.org/mailman/listinfo/spasm/>.

Source for this draft and an issue tracker can be found at <https://github.com/lamps-wg/dilithium-certificates>.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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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: a pure and a pre-hash variant. 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 standardisation, 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 a 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 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 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 following bits set:

- keyEncipherment,
- dataEncipherment,
- keyAgreement,
- encipherOnly, and
- 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 is requested to assign an object identifier (OID) for the module identifier (TBD1) with a Description of "id-mod-x509-ml-dsa-2025". The OID for the module should be allocated in the "SMI Security for PKIX Module Identifier" registry (1.3.6.1.5.5.7.0).

## 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 re-created 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` 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 亮 (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  $H(\text{tr} || m_1) = H(\text{tr} || m_2)$  since a direct hash collision  $H(m_1) = H(m_2)$  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. That 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 come with a 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 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 possess 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(TBD1) }
```

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 attack. 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 reference respectively. Levels 2 and 4 use collision search for SHA-256 and SHA-384 as reference.

The parameter sets defined for NIST security levels 2, 3 and 5 are listed in the 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

Figure 1: 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...1elf. 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-----
MDQCAQAwCwYJYIZIAWUDBAMRBCKAIAABAgMEBQYHCAkKCwwNDg8QERITFBUWFxgZ
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-----
MIIKGAIBADALBgIghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0sl9jxOX
0Xidr6FwJLMW6b7JOc4Pf3f421ZE3No2a/5HNL2V9DX/mmE6pUqkHCxpTAQymgex
+rtI9SownxGhiY+EjiMi/+Yj7IENS77jNoWFSogmnaMglRIL/P6JoY4w9xFNg6pA
SmRrbJlziYYNELIu4ABuI4SBkYZhmyYNEYZklKYOIhhEgkAomBRhSKZhTEJIoZII
wjgpUSRICKElwgxCMRxIBQJFINSGKeAhBBuycBwIrVkCLBhDacEmBJEUYhpWQBG
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TB108CFkqhREqFk
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYsUMgJMMWEGpZtSpqsmQZtpEQyIKdkWjJu
EbVwIJJhJBOOBiUsCkhyYKBR0wgqmSCAWCQgJAdOWRSIEKRkYMBt4LKNgXkJIDQi
wCRBCUNxCiEgYaIBUiJSG4CAmJQAE5NN0zIpIhcKmJJpGhRRICchnMAgYqKBSBhp
GoVNg0RpWyBBaxJCyxhGAakNDAlxg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy
UjJyVKZAWhgQDDISksKAUhJiXIIoC7RsA0KNUxAMFAEO4TZSiIQkkQIKY0YmIAYp
EcIo0CBIArNsojYJWoZiY7Rhi0ZixECCGokJEAJNJLJFIBILJmKFiCiMycBNWUgi
CiduwTRkTJBgW0RQgoZJQ4gEQ7KMYDCAoogthKRtjKYp0MaEQgZGiYhRAKmAUMN
5DgNpAaN05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdlJChiFCiQCRBh2UAiGzNg
CQKS0CSBIAQISRheoyItXIhEFJgIpeZhAZVkcZkKDJRQykBq0rIgwDgBgjCOE7kI
kYCEFIgpbBiREjUNOCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp
GiKJFEUR3IJEUJZFDESEwLIEmqYFQ4YsRDJuieQhIKhMmjBw47gtYyaIAYVJA0OM
SKgJyhRyUzROEkMIG6cEWTAi2ZSA4jQigUISnDAqlDQmYQRFJCYoE0YJSjJtESgJ
GLglYigRE0ENQbIRkIRMixISosaIycAwIgyG0hiOhIYwkERSEogx2SBxE8UoQwYO
AzBgZkaEWCZSTIgBHvclYshf+kOs+kkhfysXLXu8FGIObZgKcaq73wxF6aIG7LFC
P+4V3swXYBMAFJ2SI8lubG4fqQQfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrrhMhVI8
qP5srSlk34O+FbEI/3IdDMh7w906dZAYSw6EVmOpH8nhw8U6YdhnQgsE8JI1V108
```

```

ZaBjaPlBKV/QmSQTlG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWMl795EeB6ptCTjy
7iuzwajFldYl6ENC/eoB3CSyEa0vwoHPd+WREMerxUvwyG1IC5vidkcdydYDzumM
/as+n8+3A3klYFSePEUPp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFEyzNpOY+
SSKM0j2KHzeFbxQtK7kNsJ+Cr4kljGOQuAR6gMA2yTV+ogRvjcy1TwxSlfNCu0F9
PP6wsf0zYiwp4Uy72S4TY8ZevUUEt1EjKblnDjLhssZ6VOfxpV+Ln56gToyjpwXm
KjxeY3N0r7eutt3qYSzeKPAAIC16pONHItJ90/m4mJTQGf1dTXEZ7+NyO7oQTLi7
CYHgdN46/iANqq6tgzmzEXyRNv0Ma+rNO+994JHTS/VcRj2RiFJNO2Zy6OWA+jWej
g29vGfxBkQzlFj7jrpnrhNUU63YeY2hOpW+XkdLdSquxYWi5SMgX9loiKssOjNwD
zEr+j2cVfho2O3+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTewZz3NO/xfNLhV3MbH
eIVknp5x9DlK6g9Lcsp+2gV4uhPTGmWNLQYKmmB/ae0b5516L7HScj04+b+r4Y+O
ezzakG5Om16ULI6uspYHDr/TZJR6lAzJeL7Wazd0nmlDzXvoxJREDiuEzs/vuYwL
7fs8QeMlnSzXGX++cgxIqmxrZGXB7mPjVpwq3HREkTcLf3gm/gt3odGdZBAAdAyUR
gQa0LS73N0f1yB/kulDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD
AZxvXCfLmNomFetKilp8kysw92HniilZodi4PsY0Si9t1H52VwbQC/SnmqSbDup
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U51hlkKjM+nlk9bj9TU51CCOnmozKF
HX9lJSKpKLkX4n4tbtUITff4uv6b7HGeybAJUUAoF9+vb4xWmjgotp2noqfQtPmAA
fHEzCSaywAetg+ru5P0e2HLM0ZciAdKwJ/NUWsLTDNeLwddA/sy8b8KgRGxuM0rF
HlppCYqilEfyCfT0TKuSzMjPIdLeR4UYzQkM4meuotJ62lf9iLSXbYn7hDzcZ0mn
bKJnnmgBv6f7AxIW+1BilwS5kjk2ul3ThTERIcrfsRmV5ZtzA0z2ftA6uBOGdkjQ
JYKAh+lJqa/Ra5XXLZmx7coleqWTL/t6BwmulanA/wX7Dyu/KECe7XtfWAG+lktz
AZ4ct4UdOFHxApBnThn/sAizAcSs9kGiuxQhbhlpyr9Ste8idJaw8weZqFXRF/rT
dEpvozUD6nmLUt3X7lQmYJ2/zT8ME7FklSBR9+1KEZcZpxLjiNMoQCCB/xNUTVTS
wjev7TSvHEuo6fS964SZowZuJrvGnorwid7HFzHR3FKeqxfvc3RzTA/kdULMg4Nr
3TSgO5vImRRxYGG/uY7G5hw+1EOO3K8lJDxkcIa56nAYsNmooLAM7LAKveJJjWnC
M2EBp3LL5PVxUj9RvQWILN8li4ScwUCqH68iQjoShRzg4z/UiXWklZ+1xf5BjJOQ
gZGrbnQbd7/gLLlpjueVxGbWFWGeZEE4LG6sAYNO6atzzqgLviNceNqRvXm2+C+J
l4XWhwDTk+ZlwiJNa3oa0hMgSVZ5ra7XAWelCGZxOlMQnbe299gTBOzf2Dsxxm7y
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKqhjhzeGHKokyh4uax+GsW9pJl7cgZP
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxNhAPC5FzuZBPs
vnUn6HPkVcTmEKYYOarMC9VtJIPnjymLZqR46y9VjLr8qGvor7rrAsWyFsJNiP6k
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
      613aa54aa41c2c694c04329a07b1fabb48f52a309f11a1898f848e2322ffe623
      ec810db3bee33685854a88269da320d5120bfcfe89a18e30f7114d83aa404a64
      6b6c997389860d12522ee0006e2384819186619b260d118664d4a62822184482
      402898146148a6614c4248a19208c2382951244808a125c2083108c471201409
      14836c18a78084106ec9c07022b56408b0610c07049812445188695900462293
      2041062e42b64c01164914284c41a85180460a5116515a0820022244dc9849d1
    }
  }
}

```

3251e13065d3c08592a85112a1640039220946621cc70cd9086dd00626524085  
80443091062c50c80924c5841a966d4a982c99066da4443220a7645a326e11b5  
7020926124138e04852c0a4872c8a051d3082a99208058242024074e59148810  
a46460c06de0b28d1b1909203422c024410943710a212061a2015222521b8080  
9a340013934dd3322922170a9892691a14512027219cc02062a2814818691a85  
4d8344695b2041031242cb184601a90d0c023183b0215a224ac89205d9906904  
306a4b064ad2b2011c404081423252327254a6405a18100c321292c280521262  
5c82280bb46c03428d53100c14010ee1365288842491020a63462620062911c2  
28d0204802b36ca236095a8648cbb4618b4662c440821a890910024d24b24520  
122524c90588288cc9c04d5948220a276ec134644c90605b4450828649438804  
43b28c603080a2882d84a46d8ca629d0c68442064689885100a98d01498de438  
0da4068dd3947142b26c1a84611ba32842b42808a0711ac531e0a04c01376524  
2862142890091061d940221b3360090292d02481200408491844a3222d5c8844  
149808a446610195640b390a0c9450ca406ad2b220c0380182308e13b9089180  
84148829c0189112350da02422e20406d9c2850428121cc989180272d24029c2  
0812d8062a9994719bb8682384291a2289144511dc82445096450c4484c0b204  
9aa60543862c44326e88442120a84c9a3070e3b82d63268803254903438c48a8  
09ca147253344e1243081ba704593022d99480e234228142129c302a94342661  
04452426281346094a326d11280918b82562281113410d41b21190844c8b1212  
a2c688c9c030220606d2188e848630904452128831d9207113c52843060e0330  
60cca6845826524c88011ef72562c85ffa43acfa49217f2b172d7bbc14620e6d  
980a71aabbdf0c45e9a206ecb1423fee15decc17601300149d9223cd6e6c6elf  
a8e41fc7c64938ab68905fd3dcda50d87082e7d0d71dlbc9b2b84c85523ca8fe  
6cad294adf83be15b108ff721d0cc87bc3dd3a7590184b0e845663a91fc9e1c3  
c53a61d867420b04f092355753bc65a06368fd41295fd09924132c6f91f67964  
c142674a725c343914c4cecf58c074bcfa4558c97bf7911e07aa6d0938f2ee2b  
b3c1a8c595d635e84342fdea01dc24b211ad2fc281cf77e59110c7abc54bf0c8  
6d480b9be276471dc9d603cee98cfdab3e9fcfb703793560549ea4450fa7b33f  
b9169c44b4d25fb9c457f49791cd3da03eac96095813c105132ccda4e63e4922  
8cd23d8a1f37856f142d93b90db09f82af89258c63aab8047a80c036c9357ea2  
046f8dc6354f0c5295f342bb417d3cfef0b1fd33622c29e14cbbd92e1363c65e  
bd4504b7512329b9670e32e1b2c67a54e7f1a55f8b9f9ea04e8ca3a705e62a3c  
5e637374afb7aeb6ddea612cde28f01a202d7aa4e34722d27dd3f9b89894d019  
fd5d4d7119efe3723bba104cb8bb0981e074de3afe200daaaead826cc45f244d  
bf431afab34efbdf782474d2fd57118f646214934ed99cba3b003e8d67a3836f  
6f19fc41910ce5163ee3ae99eb84d514eb761e63684ea56f9791d2dd4aac6e61  
68b948c817f75a222acb0e8cdc03cc4afe8f67157e1a363b7faeff9f172b9891  
3677c5aldd085e9ee4c22052c1af58193116673dcd3bfc5f34b855dcc6c77885  
649e9e71f43d4aea0f4b72ca7eda0578ba13d31a658d2d060a9a66ff69ed1be7  
997a2fbl1d2723d38f9bfabe18f8e7b3cda906e4e9b5e942c8eaeb296070ebfd3  
64947a940cc978bed66b37749e6d5dcd7be8c494440e2b84cecfefb98c0bedfb  
3c41e3359d2cd7197fbe720c48aa6c6b6465c1ee63e3569c2adc744491370b7f  
7826fe0b77a1d19d64101d032b918106b42d2ef73747e5601fe4ba50f23ede52  
1f031a817d15294a43722e8378784b6db0cf1ba9e8ae911d9201b9ce9cc3019c  
6f5c27cb98da26144b64225a7c932b30f761e78a2d59ald8b83ec6344a2f6dd4  
7e765706d00bf4a79a6a926c3ba91d812c8f2c797ab1796709e5d16856778293  
529f0286d015c3b5399619642a333e9e593d6e3f5353994208e9e6a332851d7f  
652522a928b917e27e2d6d42137dfe2ebfa6fb1c67b26c0254528685f7ebdbe3

```
15a68eaa2da769e8a9f42d3e60007c71330926b2c0012d83ead4e4fd1ed872cc
d1972201d2b027f3545ac2d30cd78bcd1d740feccbc6fc2a0446c6e30eac51f5a
69098aa2d447f2085b4e4e4b92ccc26921d2de478518cd090ce267aea2d27ada
57fd88b4976d89fb843cdccf49a76ca2679e6801bfa7fb031896fb50629704b9
923936bb5dd385311121cadfb11995e59b73034cf67ed03ab813867648d02582
8087e949a9afd16b95d72d99bledca257aac132ffb7a0709aed5a9c0ff05fb0f
2bbf28409eed7b5f5801be964ced019e1cb7851d3851f10290674e19ffb008b3
01c4acf641a2bb14216eldd69cabf52b5ef227496b0f30799a855d117fad3744a
6fa33503ea798b52ddd7ee5426609dbfcd3f0c13b164d6c051f7ed4a119719a7
12e388d328402081fff1354b554d2c237afed3b151c4ba8e9f4bdeb8499a3066e
26bbc69e8af089dec71731d1dc529eab17ef7374734c0fe475494c83836bdd34
a03b9bc89914716061bfb98ec6e61c3ed4438edcaf25243c647086b9ea7018b0
d9a8a0b00cecb00abde2498d69c2336101a772cbe4f571523f51bd05882cdf35
8b849cc140aalfaf22423a12851ce0e33fd48975a4959fa5c5fe418c93908191
ab6e741b77bfe02cbd698ee795c466d615619e6441382c6eac01834ee9ab73ce
a80bbe235c78da91bd79b6f82f899785d68700d393e675c2224d6b7a1ad21320
495679adaed70167b50866713a53109db7b6f7d81304ecdfe83b319b1ef24830
6b45ad29e7ddcc863dac56048b5d69ea175011f7614c00a86a863cde1872a893
2878b9ac7e1ac5bda4997b72064f0cd75f4c814e034de11acb9013cf7ea926b4
e7eaace070c7ba2188efad2e431e1223d45dd05c4d8403c2e45cee6413ecbe75
27e873e455c4e610a61839aacc0bd56d2483e78f298b66a478eb2f558cbafca8
6be847baeb02c5b216c8cd88fea4df249b09e670a20703abac24b0a91abc4a56
46601442ba10becfd30993880051d07f56a05a9379e7a8e6befee3f22faa1063
98f7706006e42e9belef89d25c272f11a95095c587d713732284de9dbd3c7217
b0689e21d8eb0fff69668' }
}
}
```

#### C.1.1.3. Both Format

```
-----BEGIN PRIVATE KEY-----
MIIKPgIBADALBgIghkgBZQMEAxEEggoqMIIKJgQgAAECAwQFBgcICQoLDA0ODxAR
EhMUFRYXGBkaGxwdHh8EggoA17K0clSq4NtF55MNSpjSyX2PE5fReJ2voXaksxbp
vsk5zg9/d/jbVktC2jZr/kc0vZX0Nf+aYTqlSqQcLG1MBDKab7H6u0j1KjCfEaGJ
j4SOIyL/5iPsgQ2zvuM2hYVKiCadoyDVEgv8/omhjD3EU2DqkBKZGtsmXOJhg0S
Ui7gAG4jhIGRhmGbJg0RhmtUpigiGESQCciYFGFIpmFMQkihkgjCOClRJEGIoSXC
CDEIxHEgFAkUg2wYp4CEEG7JwHAitWQISGEMBwSYEkRRiG1ZAEYikyBBBi5CtkwB
FkkUKExBqFGARgpRf1FaCCACIkTcmEnRMLHhMGXTwIWSqFESoWQAOSIJRmIcxwzZ
CG3QBiZSQIWARDCRBixQyAkKxYQalm1KmCyZBm2kRDIGp2RaMm4RtXAgkmEkE44E
hSwKSHLIoFHTCCqZiIBYJCAkBO5ZFigQpGRgwG3gso0bGQkgNCLAJEEJQ3EKISBh
ogFSiIibgICaNAATk03TMikiFwqYkmkaFFegJyGcwCBiooFIGGkahU2DRGlbiEED
EkLLGEYBqQ0MAjGDsCFaIkrIkGZXkGkEMGpLBkrSsgEcQECBQjJSMnJUpkBaGBAM
MhKSwoBSEmJcgigLtGwDQo1TEAwUAQ7hNlKIhCSRAGpjRiYgBikRwiJQIEgCs2yi
NglahkjLtGGLRmLEQIIaiQkQAK0kskUgEiUkyQWIKIzJwElZSCIKJ27BNGRmkGBb
RFCCchkldiARDsoxgMICiic2EpG2MpinQxorCBkaJiFEaqY0BSY3kOA2kBo3TlHFC
smwahGEboyhCtCgIoHEaxTHgoEwBN2UkKGIUKJAJEGHZQCIBm2AJApLQJIEgBAhJ
GESjiilciEQUmAikRmEBLWQLOQoMlFDKQGrSsiDAOAGCMI4TuQiRgIQUiCnAGJES
NQ2gJCLiBAbZwoUEKBicyYkYanLSQcNCBLYBiqZlHGbuGgjhCkaIokURRHcgkRQ
```



```

lkUMRITAsgSapgVDhixEMm6IRCEggEyaMHDjuC1jJogDJUkDQ4xIqAnKFHJTNE4S
QwgbpwrZMCLZlIDiNCKBQhKcMCqUNCZhBEUKJigTRglKMM0RKAKYuCViKBETQQ1B
shGQhEyLEhKixojJwDAiBgbSGI6EhjCQRFISiDHZIHETxShDBg4DMGDMpoRYJlJM
iAEe9yViyF/6Q6z6SSF/Kxcte7wUYg5tmApqxrvfDEXpogbssUI/7hXezBdgEwAU
nZiJzW5sbh+o5B/Hxkk4q2iQX9Pc2lDYcILn0NcdG8myuEyFUjyo/mytKURfg74V
sQj/ch0MyHvD3TPlkBhLDoRWY6kfyeHDxTph2GdCCwTwkjVXU7xloGNo/UEpX9CZ
JBMSb5H2eWTBQmdKclw0ORTEzs9YwHS8r0VYyXv3kR4Hqm0JOPLuK7PBqMWV1jXo
Q0L96gHcJLIRrS/Cgc935ZEQx6vFS/DibUgLm+J2Rx3JlgPO6Yz9qz6fz7cDeTVg
VJ6kRQ+nsz+5FpxEtNJfucRX9JerZT2gPqyWCVgTwQUTLM2k5j5JIoZSPYofN4Vv
FC2TuQ2wn4KviSWMY6q4BHqAwDbJNX6iBG+NxjVPDFKV80K7QX08/rCx/TNiLCnh
TLvZLhNjxl69RQS3USMpuWcOMuGyxnpU5/GlX4ufnqB0jKOnBeYqPF5jc3Svt662
3ephLN4o8BogLXqk40ci0n3T+biYlNAZ/VlNcRnv43I7uhBMuLsJgeB03jr+IA2q
rq2CbMRfJE2/Qxr6s07733gkdNL9VxGPZGIUk07ZnLo7AD6NZ6ODb28Z/EGRDOUW
PuOumeuE1RTrdh5jaE6lb5eR0t1KrG5haLlIyBf3WiIqyw6M3APMSv6PZxV+GjY7
f67/nxcrmjE2d8Wh3QhenuTCIFLBr1gZMRZnPc07/F80uFXcxsd4hWSennH0PURq
D0tyyn7aBXi6E9MaZY0tBgqaZv9p7RvnmXovsdJyPTj5v6vhj457PNqQbk6bXpQs
jq6ylgcOv9NklHqUDML4vtZrN3SebV3Ne+jE1EQOK4TOz++5jAvt+zxB4zWdLncZ
f75yDEiqbGtKzCzHuY+NWnCrCdESRnwt/ecb+C3eh0Z1kEB0DK5GBBRQtLvc3R+Vg
H+S6UPI+3lIfAxqBfRUpSkNyLoN4eEttsM8bqeiukR2SAbnOnMMBnG9cJ8uY2iYU
S2QiWnyTKzD3YeeKLVmh2Lg+xjRKL23UfnZXBTAL9KaaPJsO6kdGsyPLHl6sXln
CeXRaFZ3gpNSnwKG0BXDtTmWGWQqMz6eWTluP1NTmUII6eajMoUdf2UliQkouRfi
filitQhN9/i6/pvscZ7JsAlRShoX369vjFaaOqi2naeip9C0+YAB8cTMJjrLAAS2D
6tTk/R7YcszRlyIB0rAn8lRawtMM14vB10D+zLxvwqBEbG4w6sUfWmkJiqLUR/II
W05OS5LMwmkh0t5HhRjNCQziZ66i0nraV/2ItJdtifuEPNzPSadsomeeaAG/p/sD
GJb7UGKXBLmSOTA7XdOFMREhyt+xGZXlm3MDTPZ+0Dq4E4Z2SNAIgoCH6Umpr9Fr
ldctmbHtyiV6rBMv+3oHCa7VqcD/BfsPK78oQJ7te19YAb6WTO0Bnhy3hr04UFEC
kGdOGf+wCLMBxKz2QaK7FCFuHWnKv1K17yJ0lrDzB5moVdEX+tN0Sm+jNQpqeYtS
3dfuVCZgnb/NPwwTsWTWwFH37UoRlxxmEuOI0yhAIiH/E1S1VNLCN6/tOxUcS6jp
9L3rhJmJbm4mu8aeivCJ3scXMDHcUp6rF+9zdHNMD+R1SUyDg2vdNKA7m8izFHFg
Yb+5jsbmHD7UQ47cryUkPGRwHrnqcBiw2aigsAzssAq94kmNacIzYQGncsvk9XFS
PlG9BYgs3zWLhJzBQKofryJCohKFHODjP9SJDASvN6XF/kGMk5CBkatudBt3v+As
vWmO55XEZtYVYZ5kQTgsbqwbG07pq3POqAu+Ilx42pG9ebb4L4mXhdaHANOT5nXC
IklrehrSEYBJVnmtrtcBZ7UIZnE6UxCdt7b32BME7N/YOzGbHvJIMgtFrSnn3cyG
PaxWBItdaeOXUBH3YUwAqGqGPN4YcqiTKHi5rH4axb2kmXtyBk8M119MgU4DTEa
y5ATz36pJrTn6qzgcMe6IYjvrS5DhHj1f3QXE2EA8LkXO5kE+y+dSfoc+RVxOYQ
phg5qswLlW0kg+ePKYtmpHjrLlWMuvyoa+hHuusCxbIWym2I/qTfJJsJ5nCiBwOr
rCSwqRq8SlZGYBRcuhC+z9MJk4gAUB/VqBak3nnqOa+/uPyL6oQY5j3cGAG5C6b
4e+J0lwnLxGpUJXFh9cTcyKE3p29PHIXSgieIdjrD/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  
9a613aa54aa41c2c694c04329a07b1fabbb48f52a309f11a1898f848e2322ffe6  
23ec810db3bee33685854a88269da320d5120bfcfe89a18e30f7114d83aa404a  
646b6c997389860d12522ee0006e2384819186619b260d118664d4a628221844  
82402898146148a6614c4248a19208c2382951244808a125c2083108c4712014  
0914836c18a78084106ec9c07022b56408b0610c070498124451886959004622  
932041062e42b64c01164914284c41a85180460a5116515a082002244dc9849  
d13251e13065d3c08592a85112a1640039220946621cc70cd9086dd006265240  
8580443091062c50c80924c5841a966d4a982c99066da4443220a7645a326e11  
b57020926124138e04852c0a4872c8a051d3082a99208058242024074e591488  
10a46460c06de0b28d1b1909203422c024410943710a212061a2015222521b80  
809a340013934dd3322922170a9892691a14512027219cc02062a2814818691a  
854d8344695b2041031242cb184601a90d0c023183b0215a224ac89205d99069  
04306a4b064ad2b2011c404081423252327254a6405a18100c321292c2805212  
625c82280bb46c03428d53100c14010ee1365288842491020a63462620062911  
c228d0204802b36ca236095a8648cbb4618b4662c440821a890910024d24b245  
20122524c90588288cc9c04d5948220a276ec134644c90605b44508286494388  
0443b28c603080a2882d84a46d8ca629d0c68442064689885100a98d01498de4  
380da4068dd3947142b26c1a84611ba32842b42808a0711ac531e0a04c013765  
242862142890091061d940221b3360090292d02481200408491844a3222d5c88  
44149808a446610195640b390a0c9450ca406ad2b220c0380182308e13b90891  
8084148829c0189112350da02422e20406d9c2850428121cc989180272d24029  
c20812d8062a9994719bb8682384291a2289144511dc82445096450c4484c0b2  
049aa60543862c44326e88442120a84c9a3070e3b82d63268803254903438c48  
a809ca147253344e1243081ba704593022d99480e234228142129c302a943426  
6104452426281346094a326d11280918b82562281113410d41b21190844c8b12  
12a2c688c9c030220606d2188e848630904452128831d9207113c52843060e03  
3060cca6845826524c88011ef72562c85ffa43acfa49217f2b172d7bbc14620e  
6d980a71aabdbf0c45e9a206ecb1423fee15decc17601300149d9223cd6e6c6e  
1fa8e41fc7c64938ab68905fd3dcda50d87082e7d0d71d1bc9b2b84c85523ca8  
fe6cad294adf83be15b108ff721d0cc87bc3dd3a7590184b0e845663a91fc9e1  
c3c53a61d867420b04f092355753bc65a06368fd41295fd09924132c6f91f679  
64c142674a725c343914c4cecf58c074bcfa4558c97bf7911e07aa6d0938f2ee  
2bb3c1a8c595d635e84342fdea01dc24b211ad2fc281cf77e59110c7abc54bf0  
c86d480b9be276471dc9d603cee98cfdab3e9fcfb703793560549ea4450fa7b3  
3fb9169c44b4d25fb9c457f49791cd3da03eac96095813c105132ccda4e63e49  
228cd23d8a1f37856f142d93b90db09f82af89258c63aab8047a80c036c9357e  
a2046f8dc6354f0c5295f342bb417d3cfefb0b1fd33622c29e14cbbd92e1363c6  
5ebd4504b7512329b9670e32e1b2c67a54e7f1a55f8b9f9ea04e8ca3a705e62a  
3c5e637374afb7aeb6ddea612cde28f01a202d7aa4e34722d27dd3f9b89894d0  
19fd5d4d7119efe3723bba104cb8bb0981e074de3afe200daaaead826cc45f24  
4dbf431afab34efbdf782474d2fd57118f646214934ed99c3ba3b003e8d67a383  
6f6f19fc41910ce5163ee3ae99eb84d514eb761e63684ea56f9791d2dd4aac6e  
6168b948c817f75a222acb0e8cdc03cc4afe8f67157e1a363b7faeff9f172b98  
913677c5aldd085e9ee4c22052c1af58193116673dcd3bfc5f34b855dcc6c778  
85649e9e71f43d4aea0f4b72ca7eda0578ba13d31a658d2d060a9a66ff69ed1b
```

```

e7997a2fb1d2723d38f9bfabe18f8e7b3cda906e4e9b5e942c8eaeb296070ebf
d364947a940cc978bed66b37749e6d5dcd7be8c494440e2b84cecfefb98c0bed
fb3c41e3359d2cd7197fbe720c48aa6c6b6465c1ee63e3569c2adc744491370b
7f7826fe0b77a1d19d64101d032b918106b42d2ef73747e5601fe4ba50f23ede
521f031a817d15294a43722e8378784b6db0cf1ba9e8ae911d9201b9ce9cc301
9c6f5c27cb98da26144b64225a7c932b30f761e78a2d59a1d8b83ec6344a2f6d
d47e765706d00bf4a79a6a926c3ba91d812c8f2c797ab1796709e5d168567782
93529f0286d015c3b5399619642a333e9e593d6e3f5353994208e9e6a332851d
7f652522a028b917e27e2d6d42137dfe2ebfa6fb1c67b26c0254528685f7ebdb
e315a68eaa2da769e8a9f42d3e60007c71330926b2c0012d83ead4e4fd1ed872
ccd1972201d2b027f3545ac2d30cd78bcl1d740fecbc6fc2a0446c6e30eac51f
5a69098aa2d447f2085b4e4e4b92ccc26921d2de478518cd090ce267aea2d27a
da57fd88b4976d89fb843cdccf49a76ca2679e6801bfa7fb031896fb50629704
b9923936bb5dd385311121cadfb11995e59b73034cf67ed03ab813867648d025
828087e949a9afd16b95d72d99b1edca257aac132ffb7a0709aed5a9c0ff05fb
0f2bbf28409eed7b5f5801be964ced019e1cb7851d3851f10290674e19fffb008
b301c4acf641a2bb14216e1d69cabf52b5ef227496b0f30799a855d117fad374
4a6fa33503ea798b52ddd7ee5426609dbfcd3f0c13b164d6c051f7ed4a119719
a712e388d328402081ff1354b554d2c237afed3b151c4ba8e9f4bdeb8499a306
6e26bbc69e8af089dec71731d1dc529eab17ef7374734c0fe475494c83836bdd
34a03b9bc89914716061bfb98ec6e61c3ed4438edcaf25243c647086b9ea7018
b0d9a8a0b00cecb00abde2498d69c2336101a772cbe4f571523f51bd05882cdf
358b849cc140aalfaf22423a12851ce0e33fd48975a4959fa5c5fe418c939081
91ab6e741b77bfe02cbd698ee795c466d615619e6441382c6eac01834ee9ab73
cea80bbe235c78da91bd79b6f82f899785d68700d393e675c2224d6b7a1ad213
20495679adaed70167b50866713a53109db7b6f7d81304ecd83b319blef248
306b45ad29e7ddcc863dac56048b5d69ea175011f7614c00a86a863cde1872a8
932878b9ac7e1ac5bda4997b72064f0cd75f4c814e034de11acb9013cf7ea926
b4e7eaace070c7ba2188efad2e431e1223d45dd05c4d8403c2e45cee6413ecbe
7527e873e455c4e610a61839aacc0bd56d2483e78f298b66a478eb2f558cbafc
a86be847baeb02c5b216c8cd88fea4df249b09e670a20703abac24b0a91abc4a
5646601442ba10becfd30993880051d07f56a05a9379e7a8e6befee3f22faa10
6398f7706006e42e9belef89d25c272f11a95095c587d713732284de9dbd3c72
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-----
MIIP2AIBADALBgIghkgBZQMEAxIEgg/EBIIPwEhoPZGXjjHrPd24sEc0gtK4il9i
WUn9jlilYeaWvUwn2FP6abgZkCPozWen2fq/kEdkb/0Ms8x/eVgFpx5w0jcbBWPj
zTNGFJyMnrzyOwpOWpAO6pxlYnkKfGPjhmPaot3bbkgNxAWh5wGui3SEhvXMHD8r
8yeXLpUQUQzVN17MCFVxdxGHIiGGI4EABCR3gGFHUAdQFxcDVQRRUSVHGDgEYXVy
IkQQiGhghkYBJ0dWcYCHBmaGQzJEQSIENjhmDQKCNjQkQyIFc2QQZFVUdyJ1VoFD
NhrivQggZDdoVGh1Q1N1EGhxgzOAVHUFJYB1KBiEOBEIcmAgIAhYgwGDYROCghIG
FxFXh2h4iHhkN1RgFlcVUIRxiGYHJzKIBmR0GFZ2IYAxgnZkFXgkUCVkJZkMRNQQ2
R4ASZnMUMBfmbLWGRxg2iGNQOEeGEQEgI1YRYTeGB4UyEkAHVHiCMENmYRZgQ1VB
goVgU2d4VjhDRDBjJhB3BzF4QnIUERZTA4UnaGdGAVCCNzUyB2YQdQRoEkGZgMD
JlIxJEVAiAaXgIh2chcwcYJHIVEngBF1RHSGYXIjM4CGYGRGg1IVhCA2gBGAIRgY
MxdzVFNIgQBEhlNnQ3BXcliDNGA4QjKfABAGBCYEJYRWajVoIFGDhjhDCEiQkVkJ
WfhncUVyYhQR4hxcYBhiDYIaGQVZQGRZQJkZwBggmYic4MXJAclcwBycohiBmdYho
JgcGQCAzaA0NmMVVGQkU0VmcYc0Vlg3AiUIRoViiAcDZwhGI3FxAAGVxdYR3hwhlVT
eCi1FEZ3KFZzAyKHABQzIGFfWEVSSZjJQJ1EzR3c4A1UWQxNHNrBmJ1F1dAJGiIFw
Z0NGgYYBdlJFMzCHIQQ0NAEDIodjUVUmUIEwd0VEQWgVQYNjZBEGQCaHMENndxKA
iEY1VFMAYkWBbf2USSEJ4A0UWZjWEN4VgFGURV0IyFDZoUir3cxNFAXg2JCBVAA
ZIRHEjRAiABgRzVAV4MzYwghBhUiUgckife0hjcGdiJYhXEmVnNHABZGroQlhwgS
JwVQCDgyACMggGY0UzYAM0afCkcGNVQANXcSJ1IwcUJTahQ3RXAFZkMiRIKFIHIY
MzAgUzcZQHcngFULMGNSUEBnM0YTGAcoBxckg3djRXMYWFFgIzNENiUWQzgWCFh3
NGJCiDAHA2WFN1UAdVixUDcCEyRjBDcIaAY2FQMDAENY1cIAhEGZHNGNSJiAzBD
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### C.1.2.3. Both Format

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10dda36f5192a816ce9c8816cc7bbfc804efc40085a3850b89f1e7fe5656dba4
10f906a97c32336c1ae7e81737a83e087354e428da8538d948dbf5dfacbf59dd2
b5fd3bc803f4ba432c9a739df2cfa9ed9484320f97edff1a48c6b86b3002cfb7
72dd5e562bc4c3d683ed964b6199fa0514b0790d958095b7b85c6be875fbb559
e1930146ccea63a388a194fe09c3dea03be52de27e901017afe809af630a7382
bf5c4cd4d1b8f41579fb4348ede4ca05f4cd3f139a31b2544e516dbe4086b9bb
4b2bed47e2d230982dd5192429d377b7c0745cc068e2f5a4aa04c7ff87209ed1
259976a0fc9b25e9e851d4e3502c02c85d6dff029e211d01ebf0e9e7188d568f
8437d813b0f122f2fb17603b693ed9c38f17cfd50b815e6d9dfc0ed2ccf19f63
99274a1420f235a59d8bf724345e14e45d9e4be8934dfc3fa92678db61d7118b
f53cb8a2225b335f7eae50e3f941237628db76d8ea38f77a72af3a26c81fe435
23b335535a5d1db7c38f341082bb5734d089e8ae309cfda3a0bcb5cd5b097113
c8edf9616aa4f6e6631b9125276fb3f680a34341c3db668dc6cad45fc93b2708
ca2af75ccce734fd191c50089dad53982fddae02531ff93e1f21ff395fc0a128
74edf06b6f9647e95a7324586c71dfd91d901d621858190fec00ccd110bbac5
9f96cb884c3c93994748a56f41283bfc41fb89052153a894588c3cb9017f3d66
326c985637e575acb812346342654025d602de3ba940c19ac1a633dffda977b5
29b8013e19c1d6d0680f4dae62c924450ae66aab82f21473061dab3d62b247f9
07e3551939ad3f5465e9d08a82bfeal7eeal1b6b2b923757477f993000b2f43b7
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-----
MIITOAIBADALBgIghkgBZQMEAxMEghMkBIITIJeSvOwvJDBoaoL8zzwvX/Z153HX
q0G5AljPp+kOyXEk2OnuTpChbGAvXsm8OFF9ww4ynVqydn09hfTJsDAPd2OJiGdQ
tXwk2z/AEuYe3lllMzc3T6cSSZFUmVJDSW0GN8s74FpZSCNb95h1+JbY/gyrMMhJ
SntNYxWgrxYKxiQ2ZCIBSBYRCReslAKJIKUsYrhFAEUqCJZwkBJuFJNw1EYQhERR
WJaRDkKpgrJByQhxxChoBJaJSECFmyJtHChkWRJBnLiRhASJRJAfyzRioIaQQCaS
IJkpEwVpXDRopDKOGSAsWUYQCaRJI0JNEjZhWBB1ASiQGjNMmYYx06JJCylQxQo
wDiBAxVNWyIGCIIdIIFSLCilw8BNpJghmEAg0UKGy0BwW7BxnJYswRIGU0YJDEUC
FEZukbQhVLCM5EZCmiCMASEle0EFWkAiE8kMoBhAUsIwyzQsS8hoG6RgSYSEYzAp
SqBpW4AE0jgKFCZM4rJEi6IRJEZJxBRSC0Jxa7IQkiiAASSI4wgrCgUoGcSBACai
3ERoQhIiRAAqySZqDlCcx4MBEMRSEGDYNETdCiHiMY7KRDJgIoaABCJJEbBMkXJhx
goRxdJJSUBAxNEIuGqgoAgIRAcCJC8cFiIRLIsJkTiiRXIJoE6VkuCCGIQqCkZRE
SCIwIjlkApieCAKIGRkpREiMIpUMoQRYBiDwEiEQQgaEG0mFiQZK0zyI28BAWLZR
DKcJjCRhmZBkjmKQWysQEKNJAYVhQzKKEZhEyLIgBDhBEEcsGcZEHCUsbIgw2UZp
myAAG0acWqSAW6BJGJAlACaC8IxWkByVMYgwbAxJLFNEJUoFAAKoMhNVKKII5iB
YJAEAhYsEyFAkYanCMKRkrQm0LQMCcZgUUQuBBEmACkRk8IIY6QxIgAowRQIDEAs
QRQGNcByVCIGiwhNoUhpeDBBHChJRBiOzJZI2UJQGwZJDEWIIwQNIDAuI4UsFACw
QLaFTMAgRIYgQBsvAJIzIhsWQYySRSEBMDQE0ko5AYJ08YQyChMIzLEUqRkzKhJ
RDgyComEADQsIoWNEDEJCTJLHImMQEApIYUACaFthMBk4gItSARAEgm04EIuk0QI
EhBqAYQFkjCKyzSOoiYuXIYRCzUIGBAAjQmJCOJ0YQAJEZgE7JJJChGGAJxoDiQ
iRRE05YtoxhAIychwBhQQ8gEQUKNXCZBRKJtSBIOQDilCxSCckguy4KIA6NgGyUm
jLggJLCFmAQhCKcsgzhkVDKJAQQBI0mEApVp0arNE6QMkUYNYZSAkDhFXMZQARcg
U8YomxgQQRJokBIhwBCEQhasU4IpgSZJ2KQFmiYkJAMp4EAm0gJIESRoEZmJmBSF
ySANUBKMHAgQAHAJAUowSiQWbSF0xrLcKbuESllGMJMITRl2DBpEDBSGTFmjBiK
yMAITJgwo6YgQRYiGAUuIiUqZLglCrMBYyCECYAJGSgOAHEBo5QR45hsWCAhCUEQ
YDYiCAZxEsKFWqCFwMaEXDgGy7ZpFISEUYKCoaZAzIYAXCYioKgImDRylCBBQ8SQ
SBZoGxZSGjccUCBCSEiKIBFB4gBswMIMFAZJETFNGQYKiUYJG4FlRMgAggZwABZy
zCRQikKJnJaQZChwkrJomCZiYZRAWraJ2EJkGiFOYpBkIcgkiyhtXEKSOMZNDIWA

```

zIhN1EKNQjSKCwRRwyaGJCWBEjUGoEQEyJSBW7QxHAGGXCQIAydgIMil4YCQGbrt  
o0YMSxhgUMYsG5ItERUEogAEIUgu2BYG0hCKg6IlCDENCThr2UhJCxZMIzIlGRkC  
SkQJ0bIhC4MsIyWfKxaFRKBEG4NQAIjYsWSAmxRlIZNgGBMK2UYNIkVhyLRAoUit  
ArgJABREm7YRC5eMQBBKghRq2pAFHAKODBlyo7SNJDBQEYcJZMYo5BiSmLRsYRZR  
QEYOHDI2iBRiDaKI7EhgpAoGhUy4hhhkgsOE7aQExNoyYRoTEBtCzMAgUZN0jgM  
BJaBpIhQApCFIrAE06Rx0oAQypZAUAzBpIQo4AhSCzCM0jgKDClRw4IJyiCR2DaS  
o6YokkIiohYBGjSGN9mmWRaYgewhz0gRhp0dfxOfBTfpxGEWFQF/ReAivHgYjnT  
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42TmTshl750g3JQHfh4WYyeoebirUWFGsqP3dDe5s8x9F66t3ITbYnRqNawJb3gv  
YqfwGqbWat3uyQsJxmmFoCMH4KHK5ZimcyTboPUvIkMidekyVwZcO35eHP4d/U0N  
8IbfISQ0FKLSfiajCoKb50tMgsFtNfeLDl4ZgzLgAHS7ZGEVqxfUyJccto5e2rA2  
nxFXs0aavYOE4tlVPxt454bh7p0LmNOfg8zs830evTqdY67HZhZKEBcaT9jGPa8Y  
LEISWMXlKapVy3664uFlIxxh9x6KDBMUENAYR+3hHTTbkfbwiqJHj9eJZ5wElJ9x  
vAFx4H46i7V1PbvapBGmNQq0bu+/hvxVHCnv5M3XZhlc9sPbItDO3eWZhURZ2X8g  
33RVvfNWOzjQ9+ttNBefyUCyXAVDt4jt2p0mgQ6sPWzJxRMnws+D6IfUCJ4ZaV4R  
rdg39vRAzDYPk/Mv7oqWY3Esa704yEq3tUgj7DY+t+QutZ/B/OYPvVUwez7IX9na  
8yBte0s5F/HIT6kuPGfYmID98uR/WgyZRZXBfwr0G6vloltNwcQt1qnbJx52TeL7  
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WbyBEPqHuo16PQFl+OQd0PgE8Rud7Q81Kl14NdBjB6jgxu9NIzBDOeHPRYkjo+ie  
Al2UU0c2bALz3WNo1OR+hdPSqXBb1XlhhS5aV5+TscUUXtN0nqEWOipJOW78tH9H  
SPapnhC/chGoLkrOGBNuKos+4KOA3NOz7z5l4bgVconWJGetSIugOSSukKHT7cvc  
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TY9PfrHmHgAodCnJlh3oMiypomKbEwnYAOkrwdxQVdzHl/M4ZusM/YlJAldUj/yo  
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8yT+/vFPCPvWWgSc0vs2JZSo4j/xomF9tbFY9vAc9Qqw7ZXG5wmEEWQQiwbhtAqw  
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```
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CFH8kxnxceoM7QuXtbn7XvmFGGvFIJj560dvZ7fMdmXUdYeXXLRaUPxkEAcZv3Y0
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F7jk5ksZPxqsUjqt8nSKNdj/vCn01Fe2+XgbCKZ6GXXQMczXFUXAA3Q0BWwkNNE+
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yvUWL2FehUkKbKNC80xDrGGj6mv+79hQ4ZDrHY2k0otezusWeMAkM+zV1IslNkBC
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VBSfFKwjPNTzoit/uPCTJb8qzo07a124oSgitoIUmmkTHMzliimECxE/x7C8xYQF
v+h/H5X/wulvxV1lZ+lDZN+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
73bd85f4c9b0300f776389886750b57c24db3fc012e61ede59753337374fa712
4991549af243496d0637cb3be05a5948235bf79875f896d8fe0cab30c84948db
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967090126e149370d446108444515896910ca92982b241c90871c42868049689
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```



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## C.1.3.3. Both Format

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-----END PRIVATE KEY-----
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  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
  }
  OCTET_STRING {
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```

## 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-----

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DCEZRtTzbmdb7Vhg+gQqMV2YJhZNapI3wlpfv0lUkKW9TfJIuVxKrneEtgVnMWas  
Qkwl1tLCCoJ6TI+YvIHjft2eDRG3v1zatOjC1JsImESQCmGDM5e8RBmzDXqXoLOH  
wZEUDMTUG1PjKpd6y28Op122W7OeWecB52lX3vby1EVZwXP3EitSBO0lwhnxaIsU  
7QvAuAGz5ugtZUPpwOn0F0TNmBW9G8iCDYuxI/BPrNGxtoXdWisbjbvz7ZM2cPCV  
oYC08ZLQixC4+rvfzCskUY4y7qCl4MkEyoRHgAg/OwzS0Li2r2e8NVuUlaJdx7Cn  
j6gOOi2/61EyiFHWB4GY6Uk2Ua54fsAlH5Irow6fUd9iptcnhM890gU5MXbfoySl  
Er2Ulw023TSlFKhnkfDrNvAUWwmrZGUbSgMTsplhGiocSIkWJlmHaKMRQGC6RENI  
bfUVIqHOiLMJhcIW+ObtF43VZ7MEoNTK+6iCooNC8XqaomrljbYwCD0sNY/fVmw/  
XWKkKFZ7yeqM6VYqDzVHSwv6jzOaJQq0388gg76077wQVeGP4VNw7ssmBWbYP/Br  
IRquxDyim1TM0A+IFaJGXvC0ZRXmfkHZEK8J7/9zkwmrWLKaFFmgC85Q0Ok4yWeP  
cusOTuX9quZtn4Vz/Jf8QrSVn0v4th14Qz6GsDNdbpGRxNi/SHs5BcEIz9asJLD0  
t9y3z1H4TQ7Wh7lerrHFM8BvDZcCPZKnCCWDe1m6bLfU5WsKh8IDhiro8xW6WSXo  
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
d8f4fff6d1a0a3a7683d65f5f5f7fc60da023e826c5f92144c02f7d1ba1075987
553ea9367fcd76d990b7fa99cd45afdb8836d43e459f5187df058479709a01ea
6835935fa70460990cd3dc1ba401ba94bab1dde41ac67ab3319dcaca06048d4c
4eef27eel3a9c17d0538f430f2d642dc2415660de78877d8d8abc72523978c04
2e4285f4319846c44126242976844c10e556ba215b5a719e59d0c6b2a96d3985
9071fdcc2cde7524a7bedae54e85b318e854e8fe2b2f3edfac9719128270aafd
1e5044c3a4fdafd9fff31f90784b8e8e4596144a0daf586511d3d9962b9ea95af
197b4e5fc60f2bled15de3a5bef5f89bdc79d91051d9b2816e74fa54531efdc1
cbe74d448857f476bcd58f21c0b653b3b76a4e076a6559a302718555cc63f748
59aabab925f023861ca8cd0f7badb2871f67d55326d7451135ad45f4a1ba6911
8fbb2c8a30eec9392ef3f977066c9add5c710cc647b1514d217d958c7017c3e9
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f2078c5b76783446defd736ad3a3702d49b089844900a61833397bc4419b30d7
a97a0b387c1911474c4d41b53e32a977acb6f0ea75db65bb39e59e701e76957d
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33670f095a180b4f192d08b10b8fabbdfcc2b24518e32eea0a5e0c904ca84478
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fdf566c3f5d62a428567bc9ea8ce95caa0f35474b0bfa8f339a250ab4dfcf208
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815a2465ef0b46515cc7e41f3124f09efff739309ab58b29a1459a00bce5038e
938c9678f72eb0e4ee5fdaae66d9f8573fc97fc42b4959f4bf8b61d78433e86b
0335d6e9191c4d8bf487b3905c108cfd6ac24b0ceb7dcb7cf51f84d0ed687b95
eaeblc533c06f0d97023d92a70825837b59ba6cb7d4e56b0a87c203862ae8f31
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-----

MIIHsJALBglghkgBZQMEAxIDggehAEhoPZGXjjHrPd24sEc0gtK4il9iWUn9j1il  
YeaWvUwn0Fs427Lt8B5mTv2Bvh6ok2iM5oqilRxZWpi7xutOie5n0sAyCVTVchLK  
xyKf8dbq8DkovVFRH42I2EdzbH3icwlZeOVBBxMWCXiGdxG/VTmgv8TDUMK+Vyuv  
DuLi+xbM/qCAKNmaxJrrtlk33c4RHNq2L/886ouiIz0eVvVfXaHnJt5j+t0q8Bax  
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gKcmmVA4Zf7Zt+5yqOF6GcQIFE9LKa/vcDHDpthXFhC0LJ9CEkWoJxl+FoErAXFZ  
tluWh+Wz6TTFilrpinm6c9KzmdclEO/60Z5TuEUPC6j84QEv2Y0mCnSqghP64kmg  
BrHDTluguILyY3giL7NvIoPCQ/D/618btBSgplV49QKVrbLyIrh8Dt7KILZje6i  
jhRcne39jq8c7y7ZSOSFD4lk9G0eONDcPd4N2mGCrB9PbtFltnQiV4Wb8i86QX7P  
H52JMXteU51YevFrnhMT4EUU/6ZLqLP/K4Mh+IEcs/sCLi9kTnCkuAovv+5gSrtz  
eQkeqObF038AoNma0DAeThwAoIEoTa/XalWjreY00kDi9sMEeA0ReeEflUGnHXP  
KKXgHHeZ2VghDdvLIm5Rr++fHeR7BzhzltP5dFa+3ghQgudKKYss1I9LMJMVXzZs  
j6YBxq+FjfoyWISRSqKYh/kDNZSaXW7apnmIKjqVlr9tlwOiH0udPYy/OEr4GqyV  
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NNXN/7KyMQUH6S/Jk64xfal/TzCc2vD2ftmdkCFVdgg4SflTskbX/ts/22dnmFC1  
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+GTAufPFVfbFQShjpAwG0dqlYr3/BXG4080Re70wCIC7pemYI5uV+pg3lkFtTzmL  
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IlkBWHEvx/RoqcL5RkA5AC0w72eLTLeYvBFiFr96mnwYugO3tY/QdRXTEVBj02FL  
56B+dEMADQ3x0sWHUziQWer8PXhczdMcB2SL7cA6XDuKlG0GTvNBpVc3Ryn8Tilt  
YuKlGRIEUwQovBUir6KP9f4WVeMEylvIwnrQ4MaJndTfKJVsFLOMyTaCzv5AK7le  
gtKcRk5E6103tI/FaN/gzG6OFrrqBeUTVZDxkpTnPoNnsCFtu4FQMLneVZE/CAOc  
QjUcWeVRXdWvjgiaFeYl6Pbe5jk4bEZJfXomMoh3TeWBp96WKbQbRCQUH5ePuDMS  
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NvvFbqQvrpfpmp6wRSGRHjDzt8eux57EakJhQT9WXW98fSdxwActjwXOanSY/utQH  
P2qfbCuK9LTDMqEDoM/6Xe6y0GLKPCff02ACa+ffFk9KRCTvdJSIBNZvRkh3Mggg  
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0zt32lLp9aWZBDnK8IOpW4M/Aq0QOIwabQ8mDABYhb1KL0dwOlrvRlKH0lOxisIl  
FDFiEP9WaBSxD4eik9bxmdPDlZmQ0MEMi09Q1fn877vyN70MKLgBgtZl10HxTxC/  
uyG7oSq2IKOjlvVsBoa06pAXmQIKiWsv6K12xKkUju+ahqNjWmqne8Hc+2+6Wad9  
/am3Uw3AyoZiYnlzc44Burjwi0kF6EqkZBvWakEM2XUgJl8vIx8rNeFesvoE0r2U  
lad6uvHg4WEBCpkAh/W0bqmIsrwFEv2g+pi9rdbEXFMB0JSDZzJltasuEPS6Ug9r  
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avXozTG+aakpbU8/017YbyIeS5P2X1kplnUzYkuSNXUMMB1ULWFNtEJpxMcWlu+  
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poebUgXXa/erpazzOvtZOX/FTmg4PWvloI6bZtpT3N4Ai7KUUFgr0TLNzEmVn9vC  
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IL9iQXGYr8ToHCjdd+1AKCMjmlUvvehryE9HW5AWcQziqrwRoGtNuskB7BbPNlyj  
8tU4E5SKaToPk+ecRspdWm3KPSjKUK0YvRP8pVBZ3ZsYX3n5xHGWpOgbIQS8RgoF  
HgLy6ERP

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

```
SEQUENCE {
  SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
  }
  BIT_STRING { '00' '48683d91978e31eb3dddb8b0473482d2b88a5f62594
9fd8f58a561e696bd4c27d05b38dbb2edf01e664efd81be1ea893688ce68aa2d
51c5958f8bbc6eb4e89ee67d2c0320954d57212cac7229ff1d6eaf03928bd515
11f8d88d847736c7de2730d5978e5410713160978867711bf5539a0bfc4c350c
2be572baf0ee2e2fb16ccfea08028d99ac49aebb75937ddcel11cdab62fff3ce
a8ba2233d1e56fbc5c5a1e726de63fadd2af016b119177fa3d971a2d9277173f
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06eed4671a44dc28d27987bb55df69e9e8561f61a80a72699503865fed9b7ee7
2a8e17a19c408144f4b29afef7031c3a6d8571610b42c9f421245a88f197e168
12b031159b65b9687e5b3e934c5225ae98a79ba73d2b399d73510effad19e53b
8450f0ba8fcel012fd98d260a74aaaa13fae249a006b1c34f5ba0b882f263782
22fb36f2283c243f0ffeb5f1bb414a0a70d55e3d40a56b6cbc88aelf03b7b288
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b9e1313e04514ffa64ba8b3ff2b8321f8811cb3fb022c8f644e70a4b80a2fbfe
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3155f366c8fa601c6af858dfa32c08491b2a29887f90335949a5d6edaa679882
a3a95d6bf6d970a221f4b9d3d8cbf384af81aac95e2b3294e04789ac83727a5d
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3a40c06d1dab562bdf0571b8d3c3917bbd300880bba5e998239b95fa91b7d64
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0f77d96172672980cfe8ff7a5a702783edc2ba31b2259015a112fc7f468a9c2f
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049d3614be7a07e744300750df1d2c58753389059eafc3d785ccdd31c07648be
dc03a5c3b8ad46d064d59c13d57374729fc4e295362e2a5191204530428bc152
2afa28ff5fel655e304ca5bc8c27ad0e0c6a39dd4df28956c14b38cc93682cef
e402bbd5e82d29c464e44eb5d37b48fc568dfe0cc6e8e16baea05e5135590f19
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a15e625e8f6dee639386c46497d7a263288774de581a7de9629b41b4424141f9
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483b8889083ace86aa7b51b1c2cfe6e2ad18d97ce36fbc56ea42fae97e6a7ac1
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63fbad4073f6a9f6c2b8af4b4c332a103a0cffa5deeb2d062ca3c215fd360026
be7c5164f4a4424ef74948804d66f46487732c8202c795478647b4ea71d627c0
86024cca354a41f0877b38f19b3774ad2095c8da53b069e21c76ae2d2007e167
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```

```
c007285bd4a2f47703a5aef465287d253b18ac22514316210ff566814b10f87a
293d6f199d3c3959990d0c1268b4f50d5f9fcefbbf237bd0c28b80182d665974
1f14f10fbfbb21bba12ab620aa2396f56c0686b4ea9017990224216b2fe8ad76c
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3738e01bab8f08b4905e84aa4641bd602410cd97520265f2f231f2b35e15eb2f
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61eebb9fae2891c774589b80e566ad557ddef7367196b7227ea9870ef09ddfec
79d6b9319a6879b5205d76bf7aba5acf33afb59d17fc54e68383d6be5a08e9b6
6da53dcde008bb294b8582bd132cdcc49959fdbc21e52721880c8ad0352c79f0
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-----

```
MIiKmjAlBgIghkgBZQMEAxMDggohAJeSvOwvJDBoaoL8zzwvX/Zl53HXq0G5AljP
p+kOyXEKpzsyO5uiGrZNDnxDP1pShv/hj4bkahiJUsRGfgSLcp5/xNEV5+SNOYlt
X+EzSQ3N3vYssweVQHS0IzblKDBeydQUH4036misgQb6vhkHBnmvYAhTcSD3B504
6pzA5ue3tMmlx0IcYPJEUboekz2xou4Wx5VZ8hs9G4MFhQqkKvuxPx9NW59INfnY
ffzrFi009Kf9xMuhdDzRyHu0ln2hbMh2S2Vp3471lvcv/6aTgV0jm/filr55063dz
ti6Phfmla1SJRvUYRPvYmAkrDab7S01YQD2iKatXgpwmCbcRENpHiPFUG5kI2Hv
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eJW9JJqpFoXeIK8yyLfiaMf5aHfQyFABElpPCo8bgmT6br5aNJ2K7K0aFimczy/Z
x7hbrOLO06oSdrph7njtfllyltznzDRYqTVAM0aru6vlagojFv7J26g7UdQv0xZ/Hg
+QhV1cZlCbIQJl3B5U7ES006fPmu8Ri0TYCRL0dRZqZlHhFs6+SSKacGLAmTH3Gr
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lSZrCC9PCckxYrM7DZ9zB6TqqlIQRdf+lm+O4+q71FlnslqBM/SWRotSuv/b+tk+
7xqYGLXkLscieIo9jTUp/Hd9K6Vwgb364B7IgwKDFB+54DVXJ2Re4QRsP5Ffaugt
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-----END PUBLIC KEY-----

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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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```

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-----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] {
  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 { '329a07b1fabb48f52a309f11a1898f848e23
22ff' }
}
}
}
}
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.17 }
}
BIT_STRING { '00' '67a8951fc308e12f6867611fdc254bf4bcb514f7f5f
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```

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beef101f232d6e97c2c4dff3f4000000000000000000000000000000000000017263843' }
}
```

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-----

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IA==

-----END CERTIFICATE-----

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    }
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    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" }
        }
      }
    }
  }
}
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}
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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    SEQUENCE {
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      BOOLEAN { TRUE }
      OCTET_STRING {
        BIT_STRING { b'1000011' }
      }
    }
  }
}

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    }
    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
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  }
}
}
}
}
SEQUENCE {
  OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.18 }
}
BIT_STRING { '00' '11816868a90c66934bdbb1d19c53a6a5dc30535ff6d
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AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
-----END CERTIFICATE-----

```

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  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 }

```

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        PrintableString { "LAMPS WG" }
    }
}
SEQUENCE {
    SEQUENCE {
        OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
    }
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b3c009ca947c39dfc82d98eb1caa4a9cbe885f786fa86e55be062222f8ba90a9
74073326b31212aece0a34a60` }
}
[3] {
  SEQUENCE {
    SEQUENCE {
      # keyUsage
      OBJECT_IDENTIFIER { 2.5.29.15 }
    }
  }
}
```

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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 { '89886750b57c24db3fc012e61ede59753337
374f' }
        }
    }
}
}
}
SEQUENCE {
    OBJECT_IDENTIFIER { 2.16.840.1.101.3.4.3.19 }
}
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4bc3e5b1020dfdfd6b28d24684ffb4f2c73805fb3c3da662aa7202b8466cc46a  
df81bbdc2703bc8d34db95f50e463d14ed5432bc3afd6de8f2e13a5fa01de0f8  
91bcb3877c1900c5052bb1aade3613709832a3dda73994c85e3ce6ed54ccf318  
3c1fbe861627e33475e00cdfbfc456a9a39842ef0bdf6ae6569fd4b395a59dd  
7d59918f5678e40ffda91c5e46e8f7eed11537c76070f8d6c2173133c3a9839f  
d59989a83c980f74814db7ebf56fe8f291a97a9e81ccc1fca049c1cdc46ecfe0  
5097efe3229495cc5caae2a06317c81626200a0ab3568358a7bf69288342de5e  
867f80111a78ec8f128702929eed1a8669f6653d08debc637ab4293f36c7f97  
bdd8a70f3c4558e24dfa2afc3ab6c7ec97637d0b6176351f45fb06ca37dade13  
eeb2715ec8f945c6bfd97762586c3blacba792af955e59348b71b2b594a608c6  
7b9f89228f2c46accb8d0cedfe090b908776f22edc10dfd36647b01776c9a508  
9f5003fadbed280eadc4cb6dca5813fff1153b0c8703b15880d8a7b38f058cc1  
fc5bf5c450e7de8b721c7ad632adbebb02c5864bba9f3a685842c206879bbcb8  
4d00dcb7fe9bbf2069792d38d12ff7180c013406d381d7c51fd06c9be308c50b  
472bc49059d116a92be0690ef14ab43d1c20c76dedf76ffe79e3a346d89b8f38  
43a87d8787c09d59c59f4cddf45c7ab1942fc738c0fe9ced0fc5b5597e328157  
288d305ee13a054558e91184cc688226e3aba1d47459211fc6ddea1a2823d11f  
e21cf97003eb261f115f27fd863d7c19b81a6f120b8460bee9af2176c5eeca7f  
75b8558e6e03a96d4d59c54b79abefe72234bf20c28aa16c554533bdf04d8913  
8cc2db43f34eleff36528e3d30facb2823fbe23e71a08357fc7b01dd1aa35abd  
7e5333557e33d03329c3ac7012e0c699db25505c3ca198a4b270d1b9e61c77  
82d4aefad06bffb9dd30bc03163bec99b439840289b2e26ec106dab49fc8054af  
74b8e1160ba4a2f5b992de20ac9153d65b0fd6df5b8c5dfa5e62c5dc174a97dc  
94ebeae4f27f101c2515f1b10021feec182d54502198e6c6c026549883de8531  
4e01f2c6719724fd87dba13cb6820c54645b2b8ad8ce2d14ecf38385380fd77e  
d1cf987af0ab39b0ab4806d55890cc99d9e1528351a33eddl1a438113d2af1c6a



4ae0c19a87d2cd38136cf32df268b4e2e71da897fe2fe1c3bcdbe87b4d4d2cf9  
122aec6dea01b6c6ece4a45e5d63fa0e5beb9612d3289ed1d5515eff83f51216  
62a4e1ea69c577a58f9a2d4d86f4bd5aca6db61c4b29f2f5278e0db04b4110f2  
662b5368f21aa957c822f0a0303ec9f56fe9030f302d16b2c4bf621ed91ab393  
645b8f9c7907c40ece541c8a0ff34cefc8b13bf187b270af0fe4346694be4b1a  
46bf806df744faa488d9d7112e9c541e27316b9bbe7ef0d15afe06fe821e4b5f  
140124ee215da5ce9a11d865bf83017cdfab6b4014e31f9da293078ddf7c5125  
4e2da95f19a508d01dc8f846b1652d4de57a7251e6393240ed14303e395fb188  
079345e0fb853f876cc1edb4290e2684cc35311e8602c71a57bd3a6c9a804591  
727be34f6fab723f48a196febc6f0f9b34f344fd9706790a3e63d1a989cbcfdf  
30f8eb71fcb024635adec568fe9d39a194c8cd2fbbf6a131390dc311e9c5381b  
5542466b3c60a8eeb621e6e653b8b52fd5dd3f8d0f3fe3f0ea948b0c7862de25  
e064c2947359fa25bd58a35e5ce33677646d0874150b72522ec6241d19d06db0  
380cd0ea8be776e7cf7ca0d1bd59c5584fece0db84d1a767a162029d682e4063  
7d7c378c847ae185e2d6dffe4e15d55baf0d35fc8d7ff56fe5fa7cbc2ee1833  
7184dc62f5e50dec5cda90629d6c81a9fedab2579019cd49dd76bf997f543bc2  
35941a70107925ff095153ec610772c5fd524c80c228d80e781e864e295d20c6  
896f502887b18ed2307e8eeaea56e2649639349652f509528e4b80ea477d7a6a  
453807b26361b1eca6fcec4e06c504166742c12f8a44a359fef2727d34f47201  
f75a7055629b28397e575e4cc9de39adc08f42410b5232f8f2e7b86fdf3e1ebb  
e734b7acba49d308a6151c1352de2e20b1fed060d5e6fb58d6f23b2847dc53b6  
7519b92dba604e448f3990570f09bd65f685545a02462cd24c72f2f7989cbe87  
b0c52da52eea1770aaecf7d568d0b1bflaed3ca8f58f332299e391b4413b6c6f  
eba11d43262177a2a446ce5afc59c48288781cf9167fe5a1bf42629c6d094c65  
37abdea5af4b4a3a7f1e8a3e8cff1026ddefc29bae39e75249364a953ec52231  
bb5813a80b3af25efca43800a74c4664632f6dc189cc2cd95478b594fc578ea3  
a15840e92822b7166c8611d464af2e8d1baa5bcaflc1649589a7eb16b889b54e  
0b7ced0ba25a51e34f4d0f152fbe69e1f43682d81a5de05f89628b1b5ef10032  
7e4b4fb3a02385762b4able721da7ff61733c41d7071e819ec44c03311474330  
e97a6c0248d1dd99419feb83980f2422a9e7c9065469c4103d76bdb7b8524c4e  
21914095fe25eea171d88dce27d96f7649a717d9415ba05138b6a26a685fb768  
f75564884fa38cc9bade16b94db62d1f9da3ce294f3e917301855676a7ee7b3f  
77bd07cfb8b53de30082bbacdf34f19e1db5aaff7a3188ef408c6a9c906b42b4  
1193003d273a5a69b0ca5844bbbc8c7812330aa3f93e155b8681f9edfba2ddb  
b011cae933e72b34d1117d26d665b195322dca63429bde4183c02255ccf0c595  
873d25c4c73db307d3165e2c0be0a6016c8785a4e83d581ec3eb0f59ed7a3832  
3d9772fdf36818aed3b485c38203fb1b019fbe0ada9099543291f106f6d2d057  
8c53734d101938945284ce689a35b3ff93fe2d40e07e31310e55d21c09cbd0db  
44a64ea3f16ed2ddc243ef5d6e5ceb4b0a81dc0564ab21e9d81cbc16c5683bad  
d91125d8b4d551f3091be2115ea121b21438033786c5b76bfc8c0e0721d0fbd7  
090541d3bdb8e99cb029a135e2ed1f6c490572e625ebce83c7fa02df21d16b0f  
b93db803cf65ebfb1380b1ba584717b6cb65fe6236adb3613d4a2b0443254dec  
83c9679ad84e2609cd475f2d9cb98a06fdfdcc73a88be0fac78c6a42e351b698  
bdc31172568deaec20964d5bc529612d580ba0a7bbcb425bffe1bf3ef1a40eb7  
504d046ba213e00a0714d11950e94b0e249e3ee6e0b6cdb4ea32b4024011a68e  
51160a133b25f99034273255916a92ea3a94fb2bcfafcc0a2e9e9dc2f8c3195d  
d0ee7c704b8bcd5d8960f2bd2160f7fd304c107d27b3b0984f50deb813a467b0  
73e6347149alcf4b5332289d635d5d23c2730b30368a5ce3ccea6155347f0df

[illegible]

#### 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-----
MIIKPgIBADALBgIghkgBZQMEAxEEggoqMIIKJgQgAAECAwQFBgcICQoLDA0ODxAR
EhMUFYRXGBkaGxwdHh8EggoAUQyb/R3XN09Oiucd1YKBEGqTQS7Y+jV/dLu0Zh7L
GSHTp1/JO4jvDmqbhRvs7BmZm+gQaMhZ1t8RXGCMFQEXDrbAVcIvYlWSSXbYlaX1
TSw4WWxAPM72+XPiKl+MfCuoNjNEcJCniyK7Qc/e2vvLLt7PkHDM5hLkKrCh8T65
3DwUkDGJwoHgsDHALISCEgi jtDDSKEoEBYDDRELgQC5EoHEBqSwDjMqSQSQYMiQA
Ii5KlmaLGAZaiMyBShkUbCEyTGIQZAG1TgAwQpChQBgogBgwjETLSxEDSEgIENIYj
lQygtkxbSJGMEoQgGQKRGIEKJRACoGlgkCgDxjCTBJARuJAERTLBIEzawpDZiCwY
RiTksAUjsWyKEIwEgXDLpDDYRmLBxhDIyEXBlgwEEgrkKGYcJXCcsohigGxiOEWE
gEyjoA0jBw7IRiAklskRgVICHATIUXghCGQsg3QNoAZgE0blmEUEIUaJkCcwIij
GBADAIgSmlGYCDiioYpAem4MJKEYGU4iAmTCMBFCFhJjFwiRo4TigCXSrmKakgAR
uA2LhgBRlnHIRiQIiUEDFUchIm4kNwMAJC7CiIUEMYxawIlCRIlYxgCZMpIbISDL
Am4YGDYxiRBNNiZkGVYOG4IIAwCFcpjFoUBtCVQwmGJGVAisk3DGCokGCKbRmgQ
NUIgNmLbNAWLSmxIEIoByI0hMA6MFCZCJAQLN4xDBilCSibYGIXIpAQUtjHRNgwi
gykAoklcuAlkiEXIAEGUOExiomjUBi7ZAg3MthFhOGTIMpJRYElSgAHgwDEAIgrB
RGaAtIRQCDASxiikCGBKsGHKxkESyGhSsHGbAAwIR2ZhGGxRFImBRoYJOUSDAjEK
kWnhIlFZRkGiBjLaBnCMZCzIjI3akpDBACDasGWCJDKDRIVcxGwAQyKJxhCjBABh
hCSjQBJRIA0YMoBBNirIsCkgRwgaEkTDtpEiKYzYMmbdlhBiJnIbRWXDpmXZwGAU
EAjQxG1JMoXQBg0RJEzjtAABqUuAM4BCMGbkGEmCNCBDGAgSBiasRILKMAHhNo5b
IiikBwZUEilLoEGYRgpmFEoKNIQgI07AFgUDRIyAtkEUKzHLJgARMG0KEg7YEGKQ
NgwUAXGJBirIJmZSBFhkBkDckiHIEHFkGC7kuABSkGiLqChLJEKRJoGZiJFUNg0K
mIG8aRx5dr9/gBkPfhWzrwn4DSmTPR/Vn0lJddemyttdtkeLCZ4DW7+GKb7Z8S4f
HY7JlsvtetEEMyRAS8/INLBzTBrGWIRQqWxf3YcrxGG51ND0lvdrYH7wnyS0ku6m
N12BMMwLEfKkmOSU747o8liHE+wiM2bPH+rG7eP6rIrB7NRY67odfeBGboLHeSdf
79U3GOWczZiFB5wtZGzNoVpiExABNaydQC40JIPvpXR0ULrErVz9y33/zj9KIZJy
+saqdCSssuX3kbavVhZQz7eytus2Aji7uSWgPb4M7FqBoFcPobHX/jVvHD8oaBt2
TOjtuObFujQUndcztr62etukrM+IwyyLR4WCpFev9qGM+ZP9TCsLbEDu/rVMVS81
dnKlkkYhy/pUgsGU2jglbTD83Wib8laAlKZgXSqLBSyP2hpmU66+mX/2gQR9rCzh
gJSFDfiIGPolnU2yelQMj8YOniHNv8I5ZRKYlmRFpDZo+QPVoXMnwTg0eF/c3UCO
PTc59SFlUpXMSPttjYLHENPlqJnHLb/PZMWlqfd+FE+i4GfHfKDH6RF3NUjPY0Jx
I1EJ5l/HxG+zK4clabd6LU4fMGnnKrNKlNSF5yoq8b68GIspz/Mnni3Z8++arXx/
hzMVayoTe6vtL0ZtyByyV26jjrxOEmpf0ZLzjkWB+Q9a+Z6QxEcTtpVlsOhnxB9w
```

```
cWFz1hzdOz1ZaMv89k3iYgajdmNIHeUQdz8wwc1621onspo5Y1zuruFSorrzz/Ru
yyg3iHNFmRv2SCNuWcziAFTSd8HBtInzNWmeqBeF7HW1hsCpRoR02ZV4iM+REFRj
qPVHh3zqURGGSdulY29uK6M2vjUp0w8NfyuvzbHIY2hJz3Py9kiZotfF4kOgU25D
11b+/IcaVavqBxCUAz9N4c29aBGZO8reC+X9kPWuNE8NY7e3j4YmPcWppZGfXnY9
PNV0pLyhLeifev2WklahcLVYLE61/cFE6qxmThkD8uTrZ7h75JmUqDmKNVjtJW5N
YS5XSZQz4bFhsdXvpED5F5jwr2NUPpZZDkjuEKXu811114F4wx98g776d6LI/zTY
a06arDBhDhmeyDQZFhMtlU575XeFZGdP11IVo4UPSCQKzc/AMxlrjNrQw2wNZJ+t
6JDEJq75MS7q5C7gvPpBd3qdmBnQwLFvYcJ8ohXcpqc1Lgw12BFNtm5L2JXXle/7
QmhVrMEkSwJznkd+bOqky9uPbI1Nr1fw0+NJBeqCJtxVvjngV3rE97E1RqzHFxaH
Qqvju+iK/j03mKXQes6be6UWIrYz8+RhZ4jwlK2nPDklHM0+0p2sNlha3BYl+Fob
uXxZug5ze+Lor7aiIiy18xn64MxZ4QBP3pFpKew3YJKoLcJSexuJlKJ8Ky5WjnJ+
skZeuWRgmW/OYyRcKyyylrgnWv0A2oyBqe8ujjv5MD2OilOq/mxtA+a8IAQ0oqOL
F00uc91QcXXoUdXnQ+ZCCeNIUg1shMyx+2v6smyMLuSFEQ3R17Br1Sgw6lu2gD0S
XMYOX6h8w0Ww9ml1Huth5xm2lmYiPLieJt3vPOyWrJNQ7pg4l/0VGBTG+1zaN5fo
paZzqkjiJn+EH7d+G8RVLGHu0gkbplrNqDAIHAIcN076b3CuBam2ngtjQzBPULSU
AqXPtG17rJg2B+fzgpKAgh8vuZLEaXP7/XeNMwNe6QsNuU9gfln7Tt+pqYpwm1gH
Wkqor1xYXy+1md2Ct3tLbznuPLFIQ3NVBkeDW+NVvpPvC+CF/NefkSuz0aBP1Ta
itxMHENeGFxR5cf0Sp43j59iGKdWbtJBCV8uWf4qRgRG8fdbfQ+11qAJEx4v8r4H
2Hsm6eS/CeZlEpe9fnobwS1BBNoczkSL+noqpxcmgAjbcEtZtsBXSJVBsj4OCdt3
fa/6IfpWRsNBIVR1aD2p/a0U/RH3FCZKDhwF2ZhBLEHEWWQOCr1v0W68/r1lFuIW
YcyqOojDEup7oFhc0k4aUwdv50HJAWk3ehaPvbP+z1z84DmyVMQjXYJl9gZShi+9
tFV4KJ8aZz/kCdufmWwtLJKHIBuVkX/hqbY08Xg4XyWv2pZpZIGeW77918wQE1MI
2Yt6grThI3sytb+dM3JvqUW79clvJ288BqRZMJSN02vUIo4vPqyM/Wcuy465qS0V
ns+zr0zC2uo3z3LqK57arYABNRm8CV2VxaOqH61GvYyUrA==
-----END PRIVATE KEY-----
```

The following is the second example:

```
-----BEGIN PRIVATE KEY-----
MIIKGAIBADALBglghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0sl9jxOX
0Xidr6FwJLMW6b7Joc4Pf3f421ZE3No2a/5HNL2V9DX/mmeE6pUqkHCxpTAQzmgeX
+rti9SownxGhiY+EjiMi/+Yj7IENS77jNoWFSogmnaMglRIL/P6JoY4w9xFNG6pA
SmRrbJlziYYNElIu4ABuI4SBkYZhmyYNEYZklKYoiHhEgkAomBRhSKZhTEJioZII
wjgpUSRICKElwgxCMRxIBQJFINSgKEAhBBuyCBwIrVklCLBhDacEmBJEUyhpWQBG
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TBl08CFkqhREqFk
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYsUMgJJMWEGpZtSpqsmQZtpeQyIKdkWjJu
EbVwIJJhJBOOBiUsCkhyYKBR0wgqmSCAWCQgJAdOWRSIEKRkYMBt4LKNgXkJIDQi
wCRBCUNxCiEgYaIBUIJSG4CAmJQAE5NN0zIpIhcKmJJPghRRICchnMAgYqKBSBhp
GoVNg0RpWyBBaxJCyxhGAakNDAlxg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy
UjJyVKZAWhgQDDISksKAUhJiXIIoC7RsA0KNUxAMFAEO4TZSiIQkkQIKY0YmIAYp
EcIo0CBIARnsojYJWoZiY7Rhi0ZixECCGokJEAJNjLJFIBILJmKFiCiMycBNWUgi
CidwTRkTJBgW0RQgozJQ4gEQ7KMYDCAoogthKrtjKYp0MaEQgZGiYhRAKmaUmnN
5DgNpAa05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdlJChiFCiQCRBh2UAiGzNg
CQKS0CSBIAQISRheoyItXiHEFJgIpeZhAZVkcZkKDJRQykBq0rIgwDgBgjCOE7kI
kYCEFIgpbBiRejUNOCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp
GiKJFEUR3IJEUJZFDESEwLIEmqYFQ4YsRDJuiEQhIKhMmjBw47gtYyaIAyVJA0OM
SKgJyhRyUzROEkMIG6cEWTAi2ZSA4jQigUISnDAqlDQmYQRFJCYoE0YJSjJtESgJ
GLglYigRE0ENQbIRkIRMixISosaIycAwIgyYG0hiOhIYwKERSEogx2SBxE8UoQwYO
```

AzBgZKaEWCZSTIGbHvclYshf+kOs+kkhfysXLXu8FGIObZgKcaq73wxF6aIG7LFC  
P+4V3swXYBMAFJ2SI81ubG4fqOQfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrhMhVI8  
qP5srSlK34O+FbEI/3IdDMh7w906dZAYSw6EVmOpH8nhw8U6YdhnQgsE8Jl1Vl08  
ZaBjaPlBKV/QmSQTLG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWML795EeB6ptCTjy  
7iuzwajFldYl6ENC/eoB3CSyEa0vwoHPd+WREMerxUvwyG1IC5vidkcdydYDzumM  
/as+n8+3A3klYFSepEUPp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFEyzNpOY+  
SSKM0j2KHzeFbxQt7kNsJ+Cr4kljGOquAR6gMA2yTV+ogRvjY1TwxSlfNCu0F9  
PP6wsf0zYiwp4Uy72S4TY8ZevUUEt1EjKblnDjLhssZ6VOfxpV+Ln56gToyjpwXm  
KjxeY3N0r7eutt3qYSzeKPAaIC16pONHItJ90/m4mJTQGf1dTXEZ7+Ny07oQTLi7  
CYHgdN46/iANqq6tgmzEXyRNv0Ma+rNO+994JHTS/VcRj2RiFJNO2Zy6OWA+jWej  
g29vGfxBkQzlFj7jrpnrhNUU63YeY2hOpW+XkdLdSquxYWi5SMgX9loiKssOjNwD  
zEr+j2cVfho2O3+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTEWZz3NO/xfNLhV3MbH  
eIVknp5x9D1K6g9Lcsp+2gV4uhPTGmWNLQYKmbb/ae0b5516L7HScj04+b+r4Y+O  
ezzakG5Om16ULI6uspYHDr/TZJR6lAzJeL7Wazd0nmlDzXvoxJREDiuEzs/vuYwL  
7fs8QeMlnSzXGX++cgxIqmxrZGXB7mPjVpWq3HREkTcLf3gm/gt3odGdZBAdAyuR  
gQa0LS73N0f1YB/kulDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD  
AZxvXCfLmNomFETkIlp8kysw92HniilZodi4PsY0Si9t1H52VwbQC/SnmngSbDup  
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U51hlkKjM+nlk9bj9TU51CCOnmozKF  
HX9lJSKpKLkX4n4tbtUITff4uv6b7HGeybAJJUoaf9+vb4xWmjgotp2noqfQtPmAA  
fHEzCSaywAetg+ru5P0e2HLM0ZciAdKwJ/NUWslTDNeLwddA/sy8b8KgRGxuMORf  
HlppCYqilEfYCFtOTkuSzMjPIdLeR4UYzQkM4meuotJ62lf9iLSXbYn7hDzcz0mn  
bKJnnmgBv6f7AxIW+1BilwS5kjk2ul3ThTERIcrfsRmV5Ztza0z2ftA6uBOGdkjQ  
JYKAh+lJqa/Ra5XXLZmx7coleqWTL/t6BwmulanA/wX7Dyu/KECe7XtfWAG+lktz  
AZ4ct4UdOFHxApBnThn/sAizAcSs9kGiuxQhbhlpyr9Ste8idJaw8weZqFXRF/rT  
dEpvozUD6nmLUt3X7lQmYJ2/zT8ME7Fk1sBR9+1KEZcZpxLjinMoQCCB/xNUTVTS  
wjev7TsVHEuo6fS964SZowZuJrvGnorwid7HFzHR3FKEqxfvc3RzTA/kdULMg4Nr  
3TSgO5vImRRxYGG/uY7G5hw+1EOO3K8lJDxkcIa56nAYsNmooLAM7LAKveJJjWnC  
M2EBp3LL5PVxUj9RvQWILN81i4ScwUCqH68iQjoShRzg4z/UiXWklZ+lx5BjJQJ  
gZGrbnQbd7/gLLlpjueVxGbWFWGeZEE4LG6sAYNO6atzzqgLvInceNqRvXm2+C+J  
l4XWhwDTk+ZlwiJNa3oa0hMgSVZ5ra7XAWelCGZxOlMQnbe299gTBOzf2Dsxxm7y  
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKhqhjzeGHKokyh4uax+GsW9pJl7cgZP  
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxNhAPC5FzuZBPs  
vnUn6HPkVcTmEKYYOarMC9VtJIPnjymLZqR46y9VjLr8qGvoR7rrAsWyFsJNiP6k  
3ySbCeZwogcdQ6wksKkavEpWRmAUQroQvs/TCZOIAFHQflagWpN556jmvv7j8i+q  
EGOY93BgBuQum+HvidJcJy8RqVCVxYfXE3MihN6dvTxyF7BoniHY6w/2lmg=  
-----END PRIVATE KEY-----

The following is the third example:

-----BEGIN PRIVATE KEY-----  
MIIKGAIBADALBgIghkgBZQMEAxEEggoEBIIKANeytHJUquDbReeTDUqY0sl9jxOX  
0Xidr6FwJLMW6b7Joc4Pf3f421ZE3No2a/5HNL2V9DX/mmeE6pUqkHCxpTAQymgex  
+rtI9SownxGhiY+EjiMi/+Yj7IENS77jNoWFSogmnaMglRIL/P6JoY4w9xFNg6pA  
SmRrbJlziYYNEliu4ABuI4SBkYZhmyYNEYZklKYoiHhEgkAomBRhSKZhTEJioZII  
wjgpUSRICKElwgxCMRxIBQJFINSGKeAhBbuycBwIrVklCLBhDacEmBJEUYhpWQBG  
IpMgQQYuQrZMARZJFChMQahRgEYKURZRWgggAiJE3JhJ0TJR4TB108CFkqhREqFk  
ADkiCUZiHMcM2Qht0AYmUkCFgEQwkQYsUMgJMMWEGpZtSpqsmQZtpeQyIKdkWjJu  
EbVwIJJhJBOOBiUsCkhyYKBR0wgqmSCAWCQgJAdOWRSIEKrkYMBt4LKNGxkJIDQi

wCRBCUNxCiEgYaIBUIJSG4CAMjQAE5NN0zIpIhcKmJjPghRRICchnMAgYqKBSBhp  
GoVNg0RpWyBBAXJCyxhGAakNDAlxg7AhWiJKyJIF2ZBpBDBqSwZK0rIBHEBAGUIy  
UjJyVKZAWhgQDDISksKAUhJiXIIoC7RsA0KNuXAMFAEO4TZSiIQkkQIKY0YmIAYp  
EcIo0CBIARnsojYJWoZiY7Rhi0ZixECCGokJEAJNJLJFIBILJMkFiCiMycBNWUgi  
CiduWTRkTJBgW0RQgozJQ4gEQ7KMYDCAoogthKRtjKYp0MaEQgZGiYhRAKmAUMN  
5DgNpAaN05RxQrJsGoRhG6MoQrQoCKBxGsUx4KBMATdlJChiFCiQCRBh2UAiGzNg  
CQKS0CSBIAQISRheoyItXiHEFJgIpeZhzAZVkcZkKDJRQykBq0rIgwDgBgjCOE7kI  
kYCEFIgpbWiRejUNoCQi4gQG2cKFBCgSHMmJGAJy0kApwggS2AYqmZRxm7hoI4Qp  
GiKJFEUR3IJEUJZFDESEWLIEmqYFQ4YsRDJuiEQhIKhMmjBw47gtYyaIAYVJA0OM  
SKgJyhRyUzROEkMIG6cEWTAi2ZSA4jQigUISnDAqLDQmYQRFJCYoE0YJSjJtESgJ  
GLglYigRE0ENQbIRKIRMixISosaIycAwIgyG0hiOhIYwKERSEogx2SBxE8UoQwYO  
AzBgZkaEWCZSTIGBH/clYshf+kOs+kkhfysXLXu8FGIOBzGKcaq73wxF6aIG7LFC  
P+4V3swXYBMAFJ2SI8lubG4fqOQfx8ZJOKtokF/T3NpQ2HCC59DXHRvJsrrhMhVI8  
qP5srSlk340+FbEI/3IdDMh7w906dZAYSw6EVmOpH8nhw8U6YdhnQgsE8JI1V108  
ZaBjaPlBKV/QmSQTlG+R9nlkwUJnSnJcNDkUxM7PWMB0vK9FWM1795EeB6ptCTjy  
7iuzwajfldYl6ENC/eoB3CSyEa0vwoHPd+WREMerxUvwyG1IC5vidkcdydYDzumM  
/as+n8+3A3klYfSepEUPp7M/uRacRLTSX7nEV/SXkc09oD6slglYE8EFEyzNpOY+  
SSKM0j2KHzeFbxQt7kNsJ+Cr4kljGOquAR6gMA2yTV+ogRvjcy1TwxSlfNCu0F9  
PP6wsf0zYiwp4Uy72S4TY8ZevUUEt1eJkblndJLhssZ6VOfxpV+Ln56gToyjpwXm  
KjxeY3N0r7eutt3qYSzeKPAaIC16pONHItJ90/m4mJTQGfldTXEZ7+NyO7oQTLi7  
CYHgdN46/iANqq6tgmgzEXyRNv0Ma+rNO+994JHTS/Vcrj2RiFJNO2Zy6OwA+jWej  
g29vGfxBkZqlFj7jrpnrhNUU63YeY2hOpW+XkdLdSquYWi5SMgX9loiKssOjNwD  
zEr+j2cvfho2O3+u/58XK5iRNnfFod0IXp7kwiBSwa9YGTEWZz3NO/xfNLhV3MbH  
eIVknp5x9D1k6g9Lcsp+2gV4uhPTGmWNLQYKmmB/ae0b5516L7HScj04+b+r4Y+O  
ezzakG5Om16ULI6uspYHDr/TZJR6lAzJeL7Wazd0nmlDzXvoxJREDiueZs/vuYwL  
7fs8QeMlnSzXGX++cgxIqmxrZGXB7mpjVpwq3HREkTcLf3gm/gt3odGdZBAaAyuR  
gQa0LS73N0flYB/kulDyPt5SHwMagX0VKUpDci6DeHhLbbDPG6norpEdkgG5zpzD  
AZxvXCfLmNomFETkIlp8kysw92Hnii1Zodi4PsY0Si9t1H52VwbQC/SnmngSbDup  
HYEsjyx5erF5Zwnl0WhWd4KTUp8ChtAVw7U51hlkKjM+nlk9bj9TU51CCOnmozKF  
HX9lJSKpKLKx4n4tbtUITff4uv6b7HGeybAJJUoaf9+vb4xWmjgotp2noqfQtPmAA  
fHEzCSaywAetg+rU5P0e2HLM0ZciAdKwJ/NUwsLTDNeLwddA/sy8b8KgRGxuMOrF  
HlppCYqilEfyCfOTkuSzMjPIdLeR4UYzQkM4meuotJ62lf9iLSXbYn7hDzcZ0mn  
bKJnnmgBv6f7AxIW+1BilwS5kj2ul3ThTERICrfsRmV5Ztza0z2ftA6uBOGdkjQ  
JYKAh+lJqa/Ra5XXLZmx7coleqWTL/t6BwmulanA/wX7Dyu/KECe7XtFwAG+lKzt  
AZ4ct4UdOFHxApBnThn/sAizAcSs9kGiuxQhbhlpyr9Ste8idJaw8weZqFXRF/rT  
dEpvozUD6nmLUt3X7lQmYJ2/zT8ME7FklSBR9+lKEZcZpxLjinMQCCB/xNUTVTS  
wjev7TSVHEuo6fS964SZowZuJrvGnorwid7HFzHR3FKeqxfvc3RzTA/kdUlmG4Nr  
3TSg05vImRRxYGG/uY7G5hw+1EO03K8lJDxkcIa56nAYsNmooLAM7LAKveJJjWnC  
M2EBp3LL5PVxUj9RvQWILN8li4ScwUCqH68iQjoShRzg4z/UiXWklZ+lx5BjJQJ  
gZGrbnQbd7/gLLlpjueVxGbWFWGeZEE4LG6sAYNO6atzzqgLviNceNqRvXm2+C+J  
l4XWhwDTk+ZlwiJNa3oa0hMgSVZ5ra7XAWelCGZxOlMQnbe299gTB0zf2Dsxxm7y  
SDBrRa0p593Mhj2sVgSLXWnqF1AR92FMAKhqhjeGHKokyh4uax+GsW9pJl7cgZP  
DNdfTIFOA03hGsuQE89+qSa05+qs4HDHuiGI760uQx4SI9Rd0FxNhAPC5FzuZBPs  
vnUn6HPkVcTmEKYYOarMC9VtJIPnjymLZqR46y9VjLr8qGvor7rrAsWyFsJNiP6k  
3ySbCeZwogCDq6wksKkavEpWRMAUQroQvs/TCZOIAFHQflagWpN556jmvv7j8i+q  
EGOY93BgBuQum+HvidJcJy8RqVCVxYfXE3MihN6dvTxyF7BoniHY6w/2lmg=  
-----END PRIVATE KEY-----

## Appendix D. Pre-hashing (External 亮-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 which 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 a External 亮 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 亮 mode, and not HashML-DSA, in PKIX for reasons laid out in Section 8.3.

Implementations of ML-DSA using the External 亮 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 亮(pk, M, ctx):

```
# Referred to as 'External 亮-ML-DSA.Prehash(pk, M, ctx)'
# in the FIPS 204 FAQ.
# M is the message, a bit-string
# 亮 and ctx are byte-strings.
# ctx is the context string, which defaults to the empty string.

亮 = 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 亮
```

Figure 2: Compute 亮 prehash operation

Sign operations:

Sign亮(sk, 亮):

```
# Referred to as 'External亮-ML-DSA.Sign(sk, 亮)'
# in the FIPS 204 FAQ.

if |亮| != 64 then
    return error # return an error indication if the input 亮 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亮_internal(sk, 亮, rnd, isExternal亮=true)
return sigma

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

Figure 3: The operations for signing 亮

There is no need to specify an External 亮 Verify() routine because this is identical to the original ML-DSA.Verify(). This makes External 亮 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 sometimes the External 亮 API without any interoperability concerns.

The External 亮 mode requires the Compute亮 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 which will fail to verify under the intended public key since a compliant Verify() routine will independently compute tr from the public key. That is not believed to be a security concern since



亮 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亮()` does not leak any bits of the secret key. The External 亮 mode also requires SHAKE256 to be available to the `Compute亮` routine.

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