# Final Steps of the NIST Lightweight Cryptography Standardization

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

C&ESAR 2023
November 21, 2023

# This Talk will cover

an overview of the NIST lightweight cryptography standardization

an update on standardization of Ascon family

# National Institute of Standards and Technology

- Part of US Department of Commerce
- Founded in 1901, known as the National Bureau of Standards (NBS) prior to 1988

**MISSION**

to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

**3,400+**
FEDERAL EMPLOYEES

**3,500+**
ASSOCIATES

**5**
NOBEL PRIZES

Laboratory Programs → Information Technology Lab → Computer Security Division

# Computer Security Division (CSD)

## Developing Crypto Standards

- International "competitions" e.g., AES, SHA-3, PQC, Lightweight Crypto
- Adoption of existing standards e.g., RSA, HMAC
- Open call for proposals: e.g., block cipher modes of operations

## CSD Publications

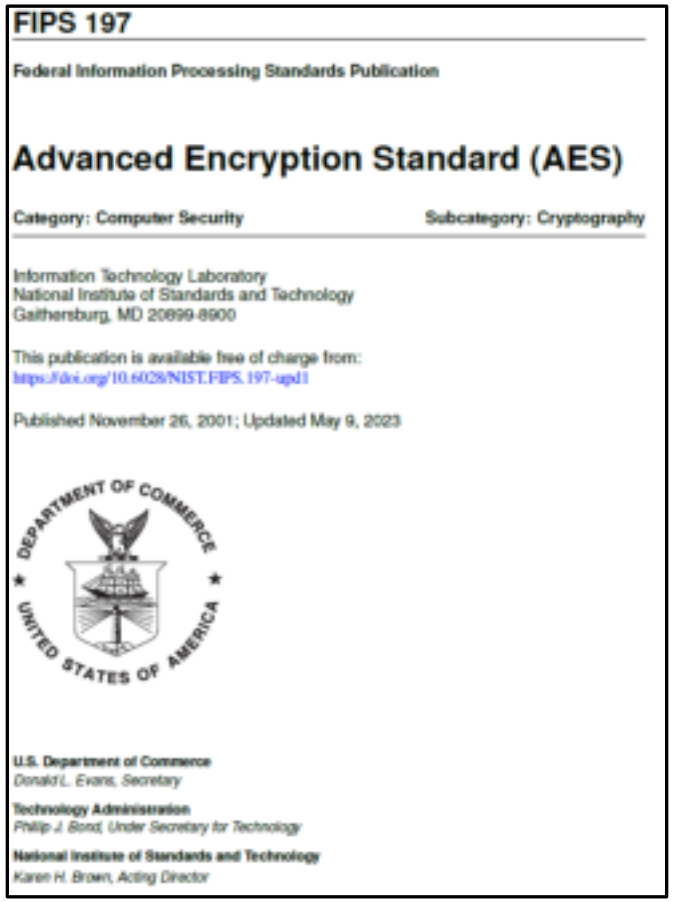
- Federal Information Processing Standards (FIPS): Specify approved crypto standards.
- NIST Special Publications (SPs): Guidelines, technical specifications, recommendations etc.
- NIST Internal or Interagency Reports (IR): Reports of research findings.

## Principles

Transparency, openness, balance, integrity, technical merit, global acceptability, usability, continuous improvement, innovation etc.

# Advanced Encryption Standard (AES)

- FIPS 197 Advanced Encryption Standard – Published in 2001.
- Reviewed[1] after 20 years and updated in May 2023.
- Widely adopted, with significant impact on economy[2]
- Instantiated with a *mode of operation* from SP 800-38 series (e.g., CBC, OFB, CBC, GCM, …)



FIPS 197

Federal Information Processing Standards Publication

**Advanced Encryption Standard (AES)**

Category: Computer Security — Subcategory: Cryptography

Information Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8900

This publication is available free of charge from:
https://doi.org/10.6028/NIST.FIPS.197-upd1

Published November 26, 2001; Updated May 9, 2023

U.S. Department of Commerce
*Donald L. Evans, Secretary*

Technology Administration
*Philip J. Bond, Under Secretary for Technology*

National Institute of Standards and Technology
*Karen H. Brown, Acting Director*

1. NIST IR 8319 & Publication Reviews https://csrc.nist.gov/projects/crypto-publication-review-project/completed-reviews
2. Smid, Development of the Advanced Encryption Standard, 2021
3. Leech et al., *The Economic Impacts of the Advanced Encryption Standard*, 2018

# Why do we need more symmetric-key primitives?

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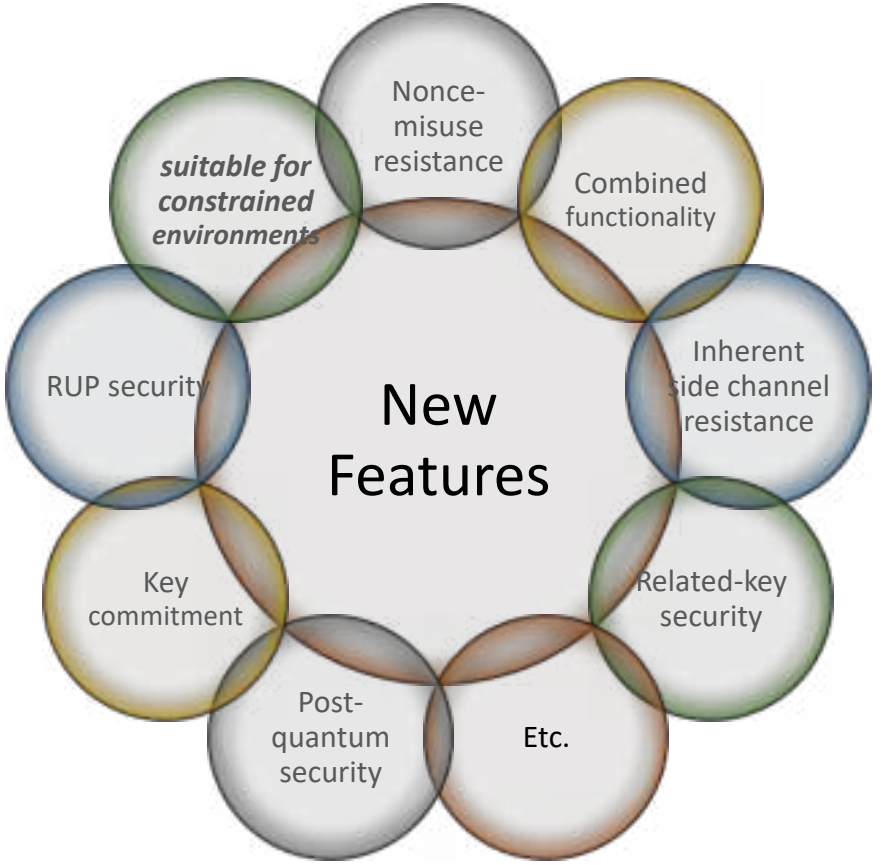

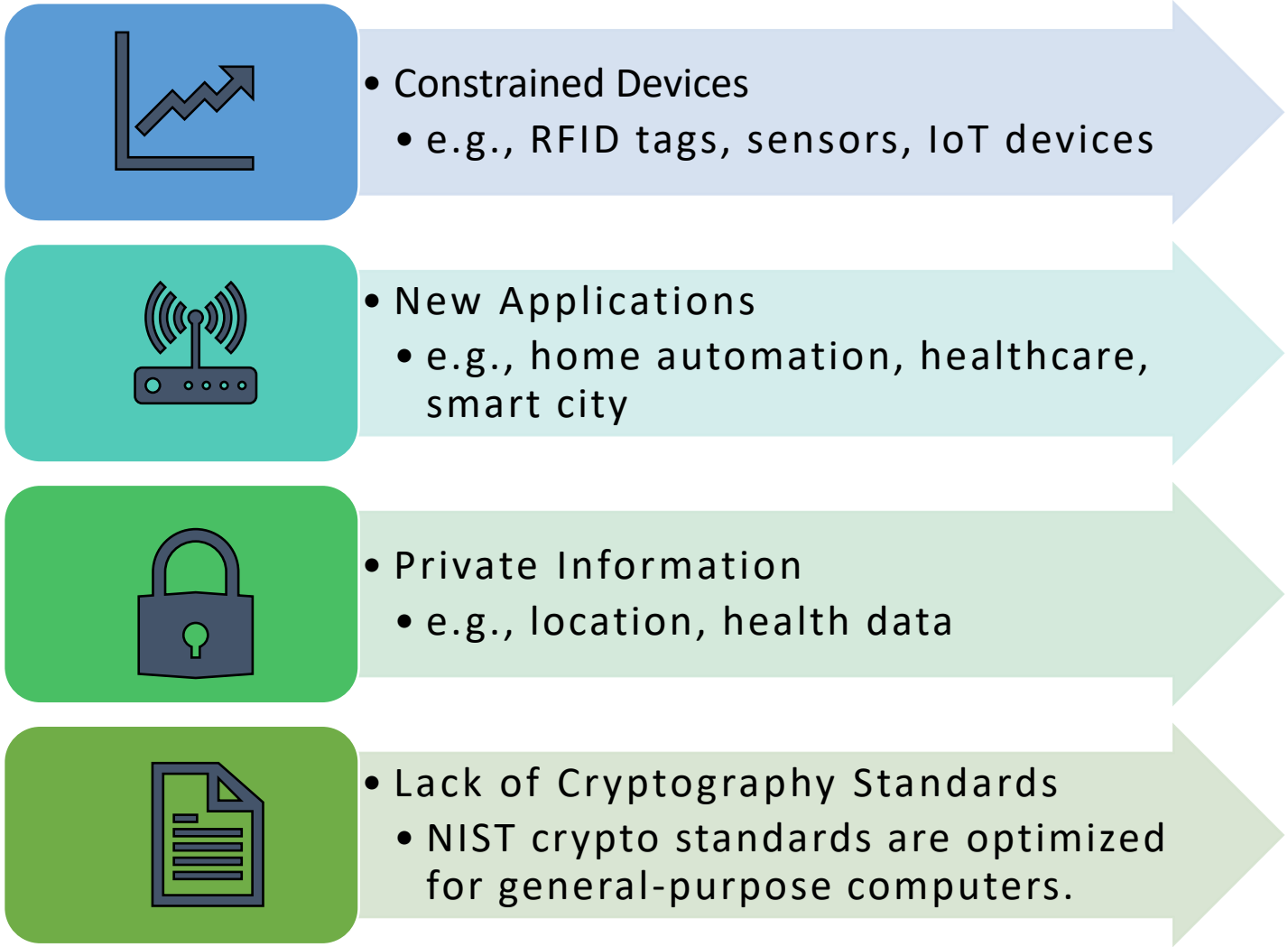
• Constrained Devices
• e.g., RFID tags, sensors, IoT devices
• New Applications
• e.g., home automation, healthcare, smart city
• Private Information
• e.g., location, health data
• Lack of Cryptography Standards
• NIST crypto standards are optimized for general-purpose computers.

## PROCESS

Public competition-like process with multiple rounds like AES, SHA3 and PQC standardization

## GOAL

Develop new guidelines, recommendations and standards optimized for constrained devices

## SCOPE

Authenticated Encryption and (optional) hashing for constrained software and hardware environments

Initial Phase
(July 2015 – August 2018)

Submission Call
(August 2018 – April 2019)

Round 1
(April 2019 – August 2019)

Round 2
(August 2019 – March 2021)

Final Round
(March 2021 – February 2023)

**Initial Phase**
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(March 2021 – February 2023)

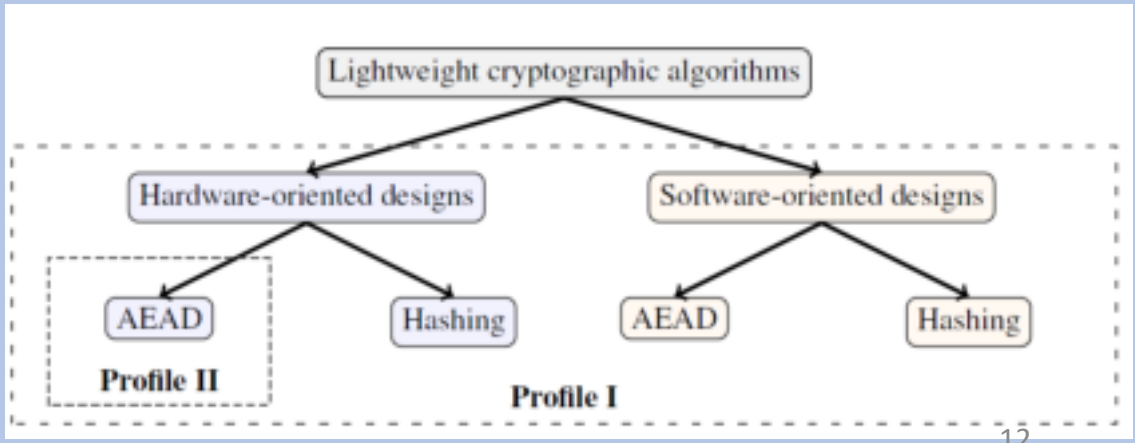
**Workshops:**

- First Lightweight Cryptography Workshop
  July 20 – 21, 2015
- Second Lightweight Cryptography Workshop
  October 17 – 18, 2016

to get feedback on target applications, industry need, requirements, etc.

**Publications:**

- NISTIR 8114 *Report on Lightweight Cryptography*
- (White paper, retired) *Profiles for the Lightweight Cryptography Standardization Process*



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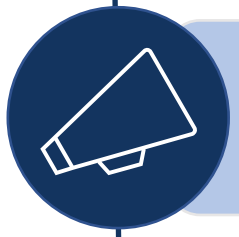

**Submission Call**
**(August 2018 – April 2019)**

Round 1
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Final Round
(March 2021 – February 2023)

In August 2018, NIST published '*Submission Requirements and Evaluation Criteria for the Lightweight Cryptography Standardization Process*'.

**Submission deadline**: February 2019

### Security requirements

At least 112-bit security level for messages up to $2^{50}$ bytes, (nonce respecting). Key size at least 128 bits.

### Design requirements

Perform better than NIST standards (AES-GCM, SHA-2), optimized for short messages etc.

### Implementation requirements

Reference and optimized implementation compatible with API etc.

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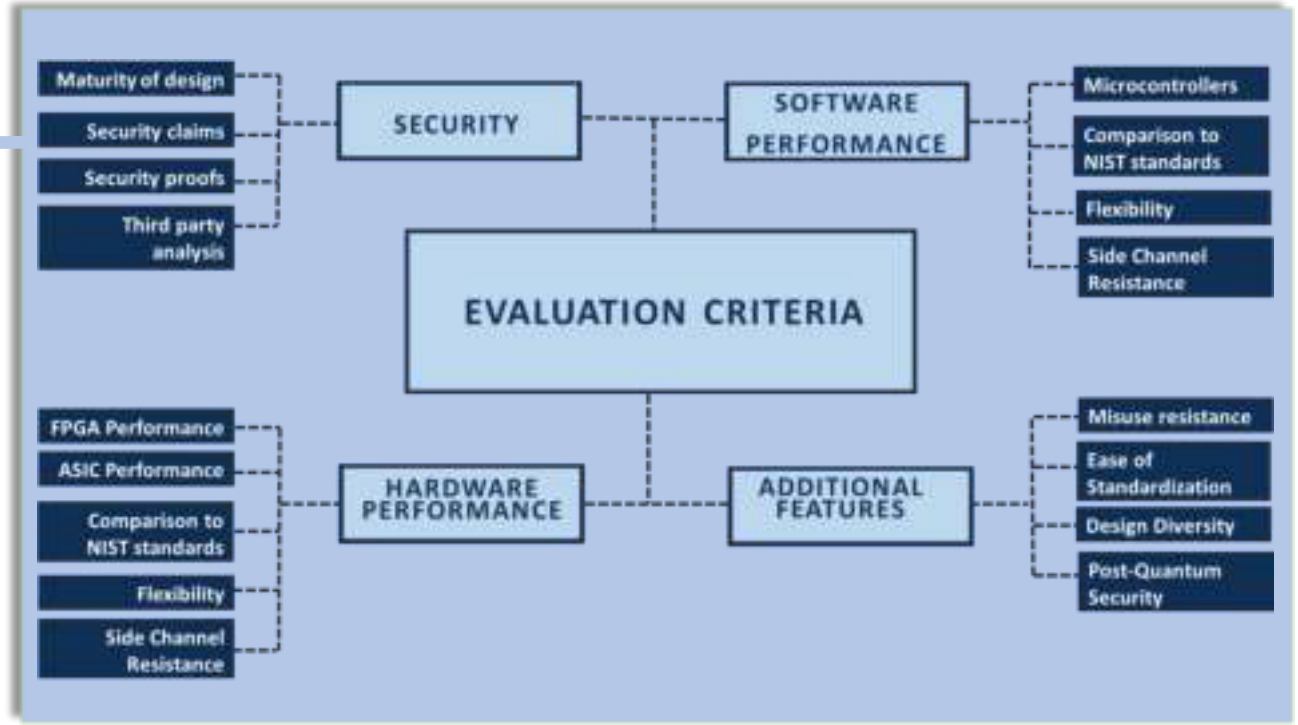

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**Round 1**
**(April 2019 – August 2019)**

Round 2
(August 2019 – March 2021)

Final Round
(March 2021 – February 2023)

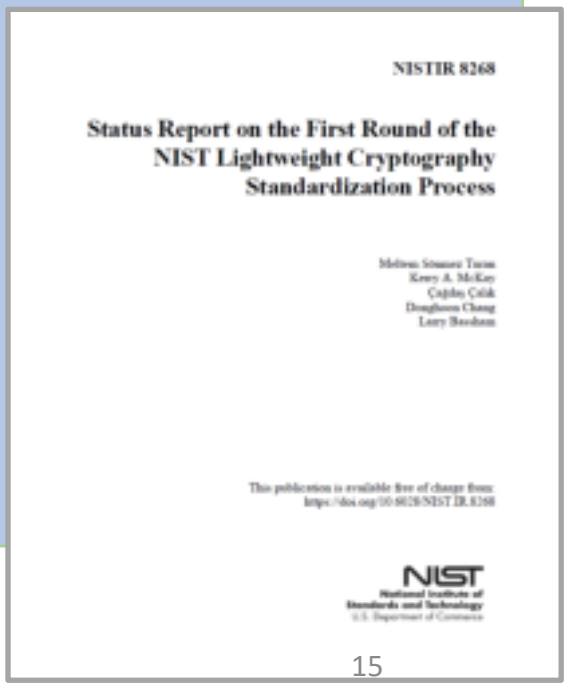
Around 4 months

56 First-round candidates

Evaluation of the candidates were done based on their security

- e.g., distinguishing attacks, practical tag forgeries, domain separation issues, new designs with no third-party analysis etc.

**NIST IR 8268** explains how 32 candidates (out of 56) were selected to move forward to the second round.


NISTIR 8268

Status Report on the First Round of the NIST Lightweight Cryptography Standardization Process

Initial Phase
(July 2015 – August 2018)

Submission Call
(August 2018 – April 2019)

Round 1
(April 2019 – August 2019)

**Round 2**
**(August 2019 – March 2021)**

Final Round
(March 2021 – February 2023)

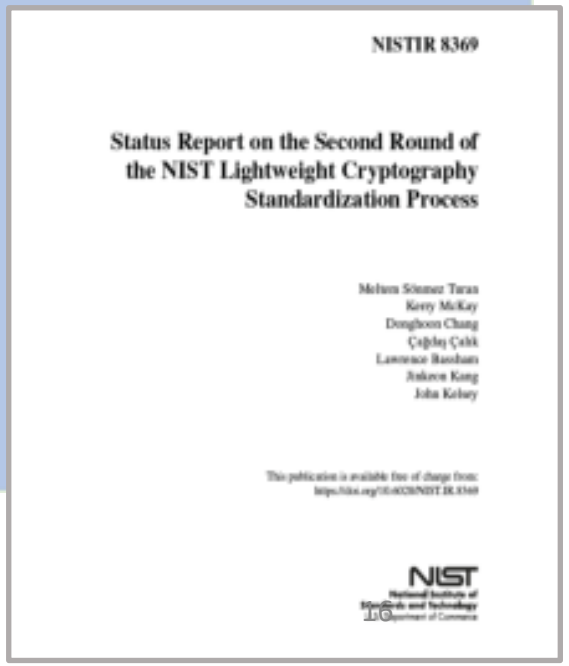
Around 20 months

32 Second-round candidates

**Workshops:**

- Third Lightweight Cryptography Workshop
  November 4 – 6, 2019
- Fourth Lightweight Cryptography Workshop 2016
  October 19 – 21, 2020

**NIST IR 8369** explains how
10 finalists were selected
to move forward to
the final round.


NISTIR 8369

Status Report on the Second Round of the NIST Lightweight Cryptography Standardization Process

Meltem Sönmez Turan
Kerry McKay
Donghoon Chang
Çağdaş Çalık
Lawrence Bassham
Jinkeon Kang
John Kelsey

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NIST

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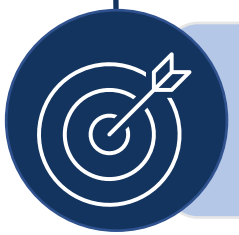


**Final Round**
**(March 2021 – February 2023)**

Evaluation of ten finalists took about two years.

| | |
|---|---|
| Ascon | Photon-Beetle |
| Elephant | Romulus |
| GIFT-COFB | Sparkle |
| Grain-128AEAD | TinyJambu |
| ISAP | Xoodyak |

Fair evaluation of finalists is challenging:

- Assigning different weights for different criteria
- Different security claims, different functionality, attacks with different complexities etc.
- Limited resources (not all algorithms got the same attention from the crypto community) for security analysis and benchmarking.

Decision relied on publicly available analysis and benchmarking results.

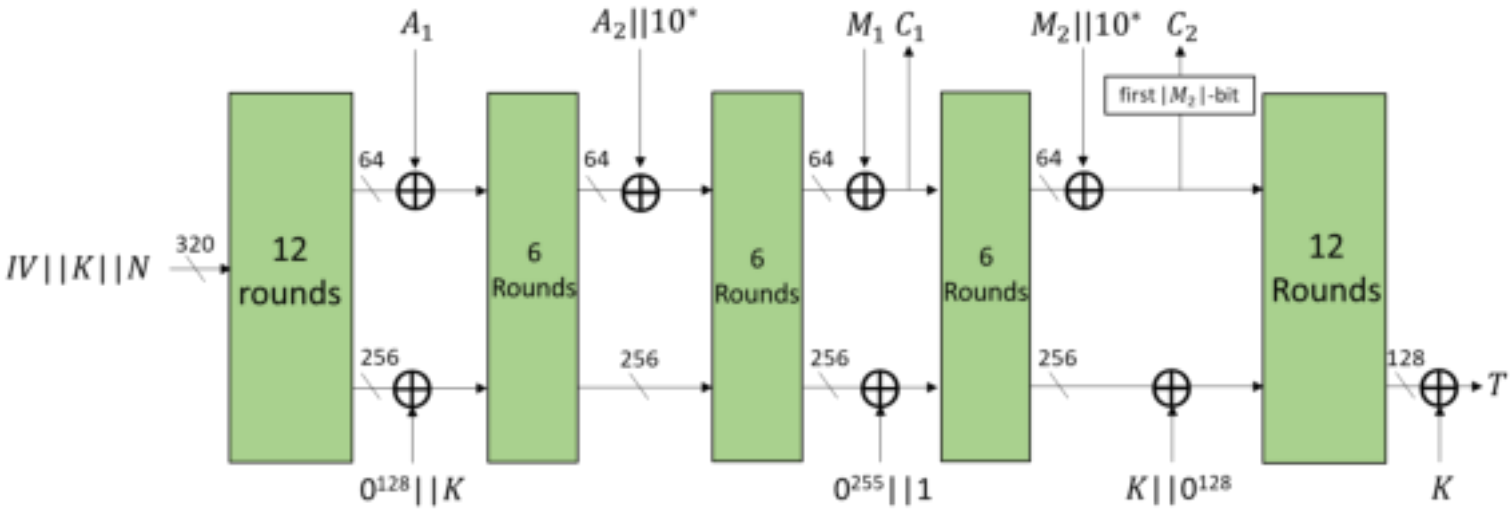
| *Finalists* | *Variant* | *Building Block* | *Mode* | *Key size* | *Nonce Size* | *Tag Size* |
|---|---|---|---|---|---|---|
| ASCON | ASCON-128 | ASCON Permutation | MonkeyDuplex | 128 | 128 | 128 |
| | ASCON-128a | | | 128 | 128 | 128 |
| | ASCON-80pq | | | 160 | 128 | 128 |
| Elephant | Dumbo | Spongent-$\pi$[160] | Encrypt-then-MAC | 128 | 96 | 64 |
| | Jumbo | Spongent-$\pi$[176] | | 128 | 96 | 64 |
| | Delirium | KECCAK-$f$[200] | | 128 | 96 | 128 |
| GIFT-COFB | GIFT-COFB | GIFT-128 | Combined Feedback | 128 | 128 | 128 |
| Grain-128AEAD | Grain-128AEAD | Feedback shift register | Encrypt-and-MAC | 128 | 96 | 64 |
| ISAP | ISAP-A-128a | ASCON Permutation | Encrypt-then-MAC | 128 | 128 | 128 |
| | ISAP-K-128a | KECCAK-$f$[400] | | 128 | 128 | 128 |
| | ISAP-A-128 | ASCON Permutation | | 128 | 128 | 128 |
| | ISAP-K-128 | KECCAK-$f$[400] | | 128 | 128 | 128 |
| PHOTON-Beetle | PHOTON-Beetle-AEAD[128] | $\text{PHOTON}_{256}$ Permutation | Sponge with Combined Feedback | 128 | 128 | 128 |
| | PHOTON-Beetle-AEAD[32] | | | 128 | 128 | 128 |
| Romulus | Romulus-N | Skinny-128-384+ Tweakable Block Cipher | Combined Feedback | 128 | 128 | 128 |
| | Romulus-M | | MAC-then-Encrypt | 128 | 128 | 128 |
| | Romulus-T | | Encrypt-then-MAC | 128 | 128 | 128 |
| SPARKLE | SCHWAEMM256-128 | $\text{SPARKLE}_{384}$ | Sponge with Combined Feedback | 128 | 256 | 128 |
| | SCHWAEMM128-128 | $\text{SPARKLE}_{256}$ | | 128 | 128 | 128 |
| | SCHWAEMM192-192 | $\text{SPARKLE}_{384}$ | | 192 | 192 | 192 |
| | SCHWAEMM256-256 | $\text{SPARKLE}_{512}$ | | 256 | 256 | 256 |
| TinyJAMBU | TinyJAMBU-128 | Keyed Permutation | Sponge | 128 | 96 | 64 |
| | TinyJAMBU-192 | | | 192 | 96 | 64 |
| | TinyJAMBU-256 | | | 256 | 96 | 64 |
| Xoodyak | Xoodyakv1 | Xoodoo Permutation | Sponge-variant Cyclist | 128 | 128 | 128 |

| *Finalists* | *Variant* | *Building Block* | *Mode* | *Digest size* |
|---|---|---|---|---|
| ASCON | ASCON-Hash<br>ASCON-Hasha | ASCON Permutation | Sponge | 256<br>256 |
| PHOTON-Beetle | PHOTON-Beetle-Hash[32] | $PHOTON_{256}$ Permutation | Sponge | 256 |
| Romulus | Romulus-H | Skinny-128-384+ | MDPH[1] | 256 |
| SPARKLE | ESCH256<br>ESCH384 | $SPARKLE_{384}$<br>$SPARKLE_{512}$ | Sponge | 256<br>384 |
| Xoodyak | Xoodyak | Xoodoo Permutation | Sponge | 256 |

# ASCON

- Permutation-based (320-bit) AEAD and hashing scheme (fixed or variable output length)
- AEAD: MonkeyDuplex mode with keyed initialization and finalization, Hash: Sponge
- No design tweak, new variant added in the final round
- Included in the final portfolio of CAESAR for lightweight authenticated encryption

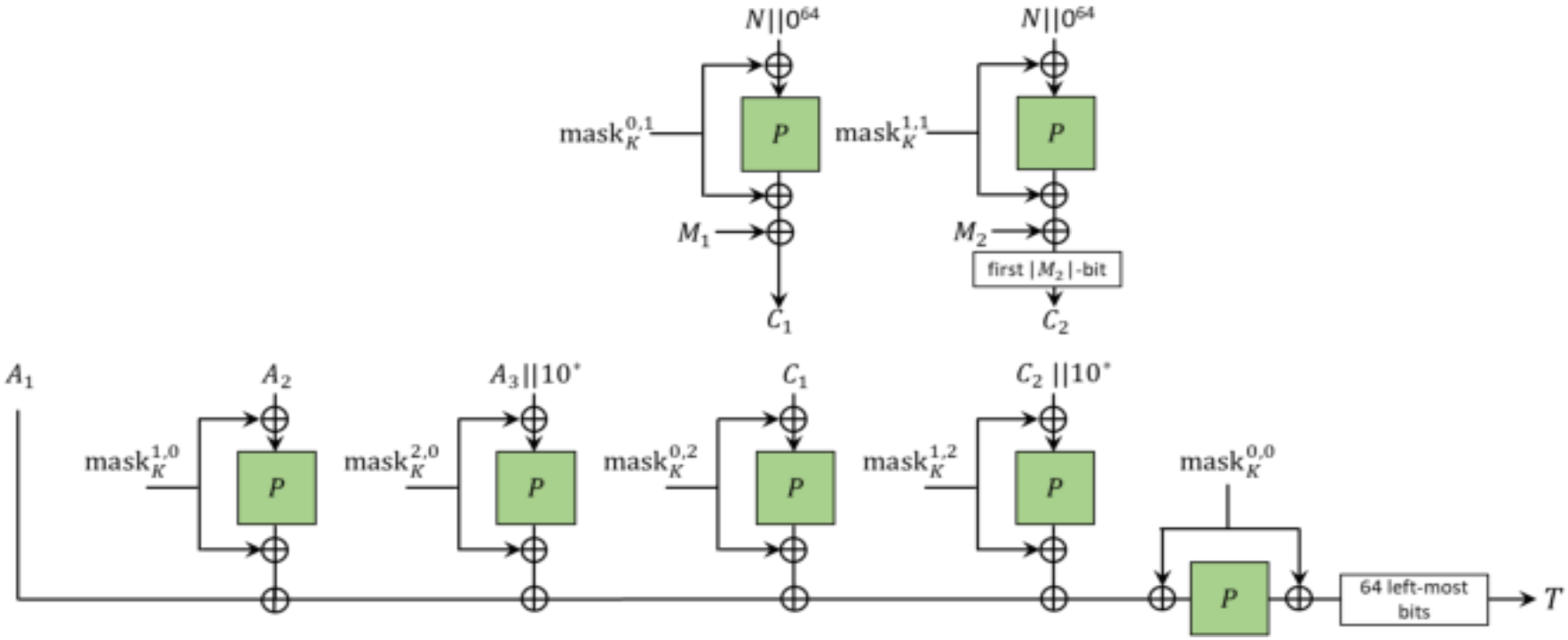
| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **Ascon-128** | 128-bit key/nonce/tag |
| | Ascon-128a | 128-bit key/nonce/tag |
| | Ascon-80-pq | 160-bit key, 128-bit nonce/tag |
| Hash | **Ascon-hash** | 256-bit digest |
| | Ascon-hasha | 256-bit digest |
| XOF | Ascon-XOF | Arbitrary length digest |
| | Ascon-XOFa | Arbitrary length digest |



# ELEPHANT

- Permutation-based (Spongent and Keccak[200]) AEAD scheme
- Nonce-based Encrypt-then-MAC mode
- Only finalist with a parallel mode
- Design tweak: Mode slightly modified to achieve authenticity under nonce-reuse.

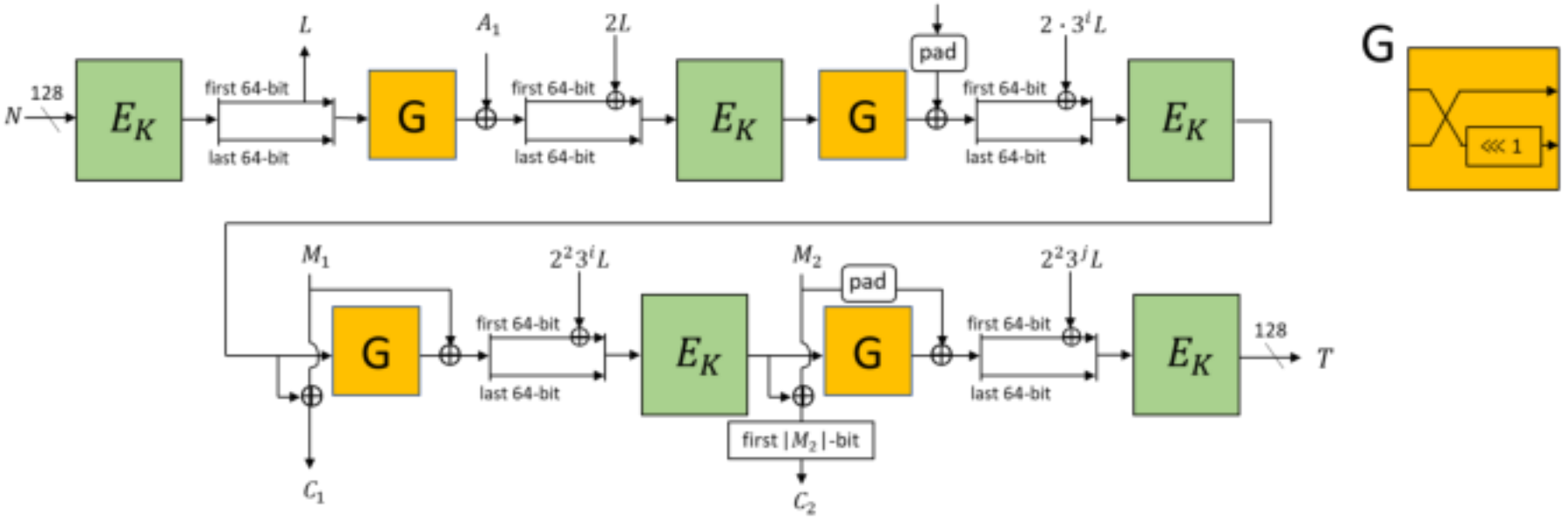
| Variant | Parameter sizes |
|---|---|
| **Dumbo** | 128-bit key, 96-bit nonce, 64-bit tag |
| Jumbo | 128-bit key, 96-bit nonce, 64-bit tag |
| Delirium | 128-bit key, 96-bit nonce, 128-bit tag |



# GIFT-COFB

- Block-cipher (GIFT-128) based AEAD scheme
- Combined Feedback (COFB) mode
- No design tweak

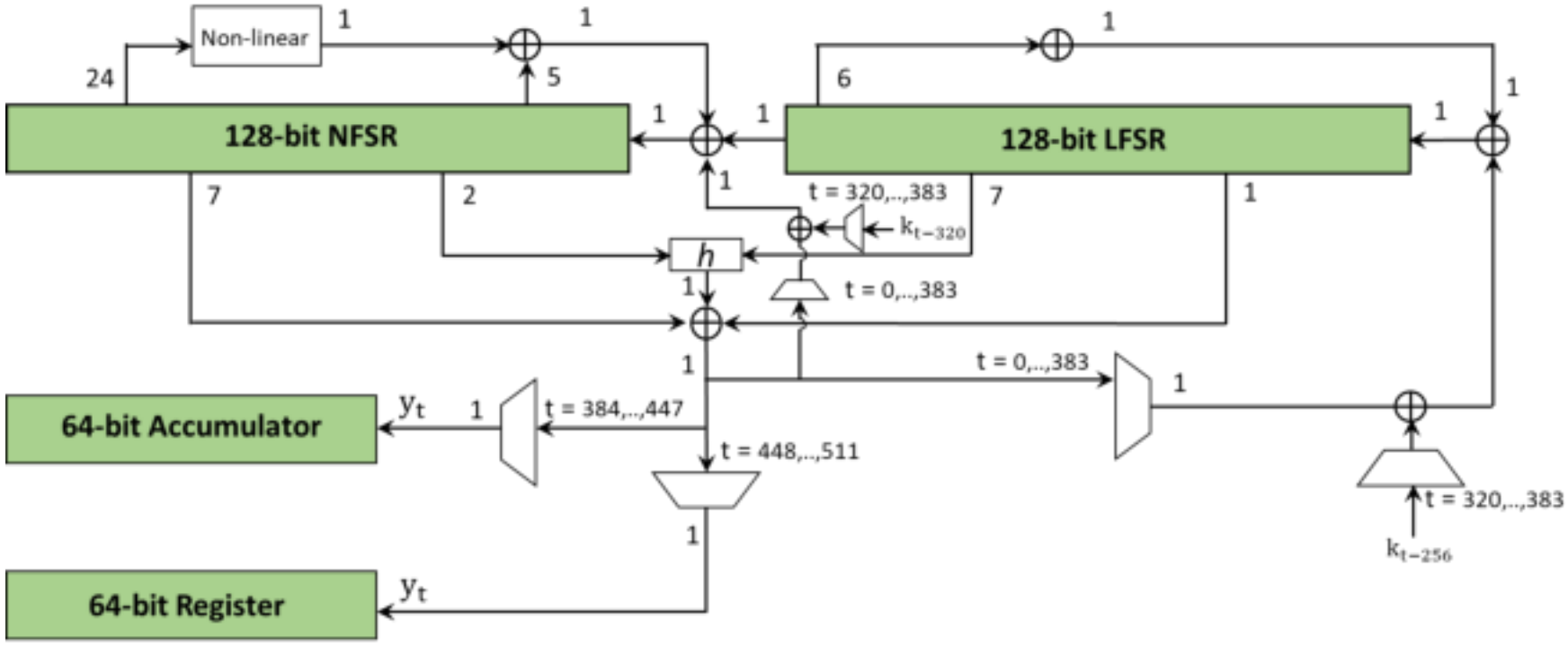
| Variant | Parameter sizes |
|---|---|
| Gift-COFB | 128-bit key/nonce/tag |



# Grain-128AEAD

- Feedback shift register based AEAD scheme
- Design tweak on the initialization part
- (Earlier versions) Part of eSTREAM portfolio, included in ISO/IEC 29167-13:2005

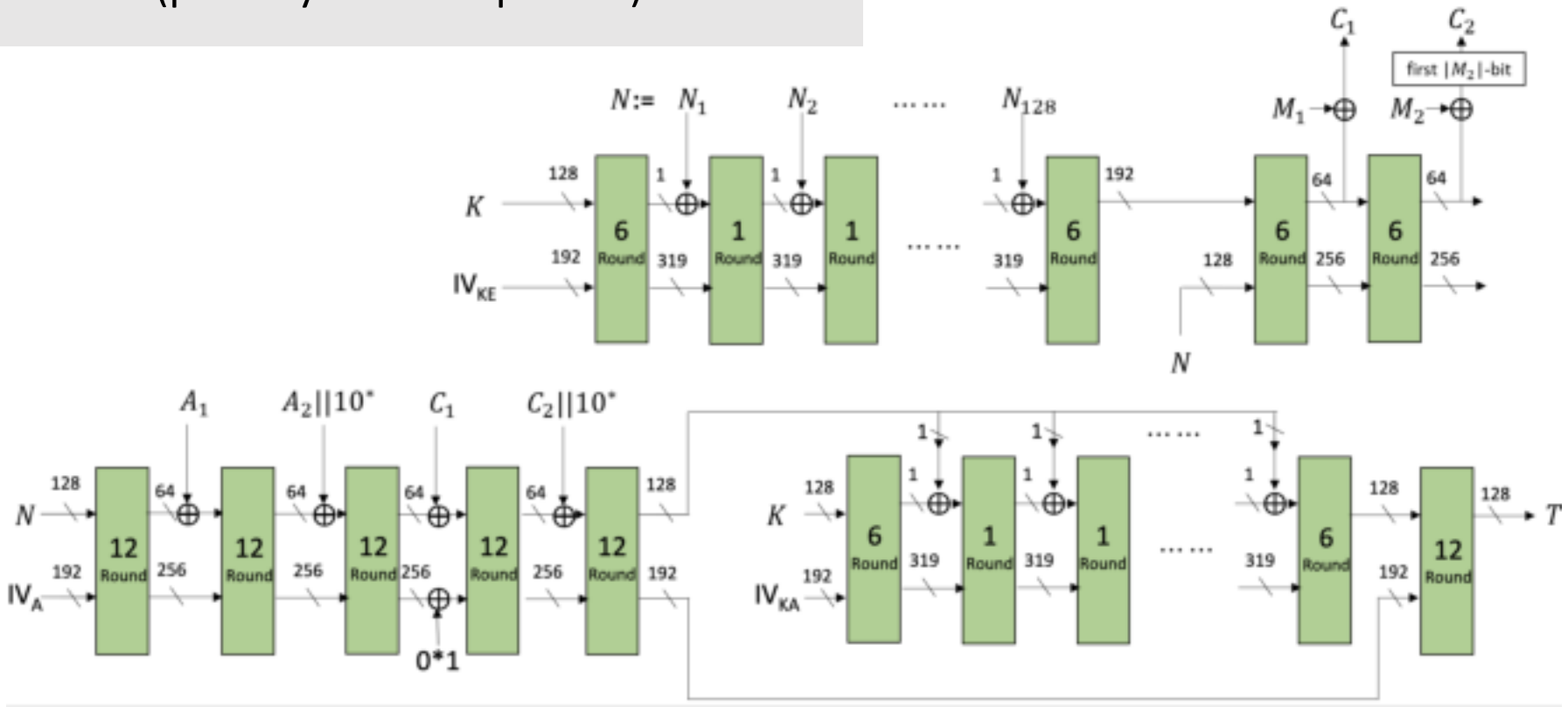
| Variant | Parameter sizes |
|---|---|
| Grain-128AEAD | 128-bit key, 96-bit nonce, 64-bit tag |



# ISAP

- Permutation-based (Ascon and Keccak permutations) AEAD scheme
- Can be paired with Ascon Hash
- Nonce-based Encrypt-then-MAC mode
- Algorithm-level security against implementation attacks
- No design tweak (primary variant updated)

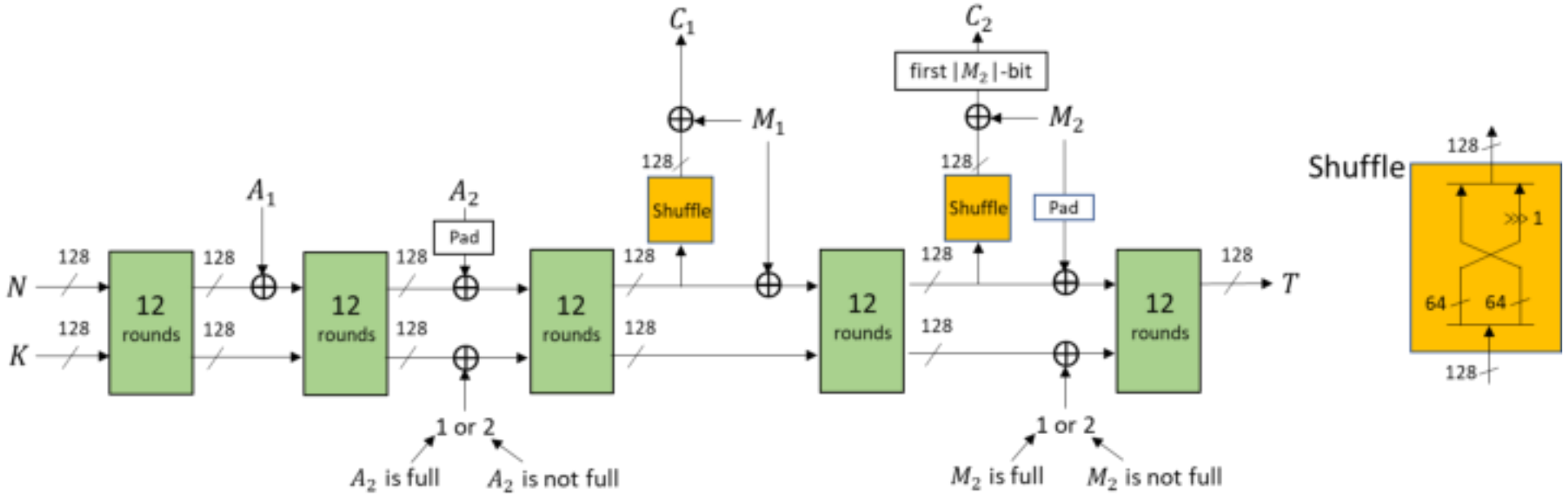
| Variant | Parameter sizes |
|---|---|
| **ISAP-A-128a** | 128-bit key/nonce/tag |
| ISAP-K-128a | 128-bit key/nonce/tag |
| ISAP-A-128 | 128-bit key/nonce/tag |
| ISAP-K-128 | 128-bit key/nonce/tag |



# PHOTON-Beetle

- Family of permutation-based (256-bit Photon permutation) AEAD & hashing scheme
- Sponge-like mode with a combined feedback.
- No design tweak

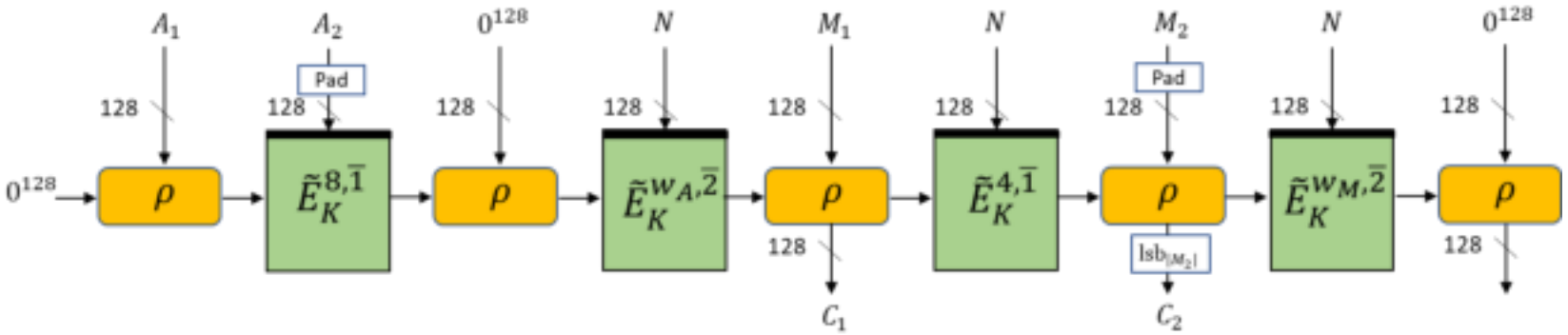
| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **Photon-Beetle-AEAD[128]** | 128-bit key/nonce/tag |
| | Photon-Beetle-AEAD[32] | 128-bit key/nonce/tag |
| Hash | **Photon-Beetle-Hash[32]** | 256-bit digest |

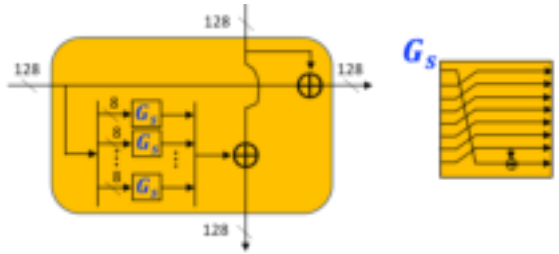


# ROMULUS

- Family of tweakable-block-cipher (Skinny) based AEAD & hashing
- Romulus-N: rate-1 TBC-based combined feedback, Romulus-M: MAC-then-Encrypt
- Nonce-misuse and nonce-respecting variants
- Design tweak to reduce the number of rounds from 56 to 40, removal of non-primary variants, addition of new variants.

| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **Romulus-N** | 128-bit key/nonce/tag |
| | Romulus-M | 128-bit key/nonce/tag |
| | Romulus-T | 128-bit key/nonce/tag |
| Hash | **Romulus-H** | 256-bit digest |

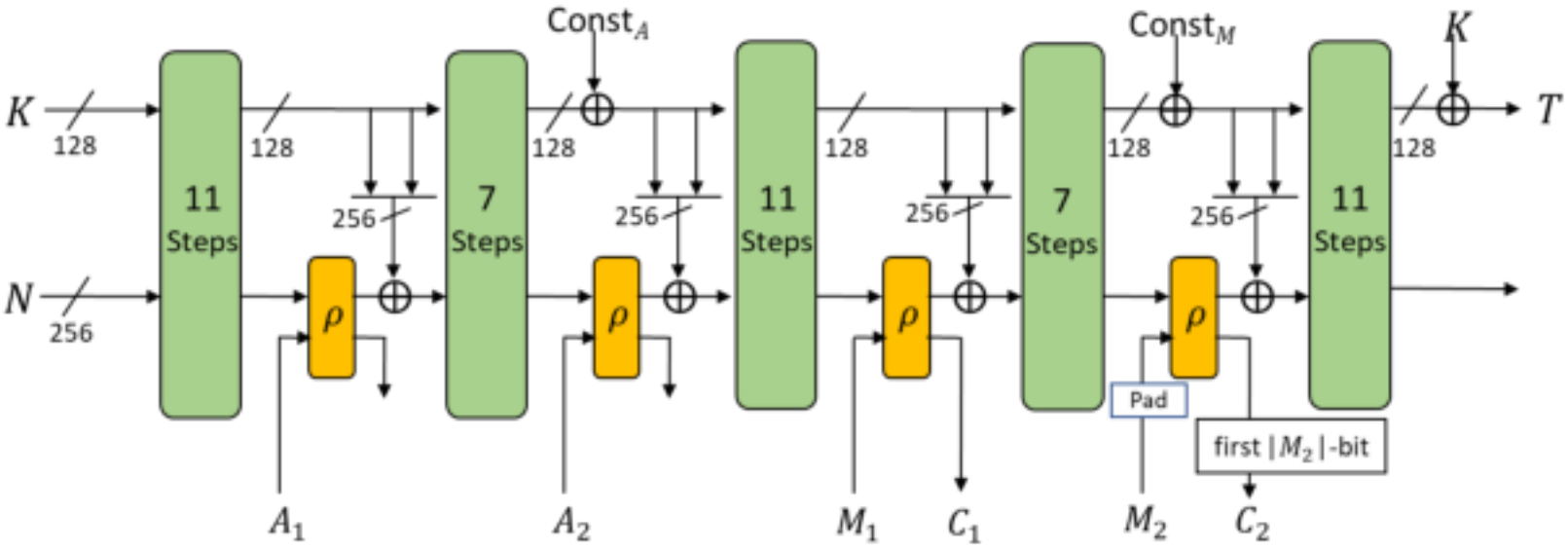


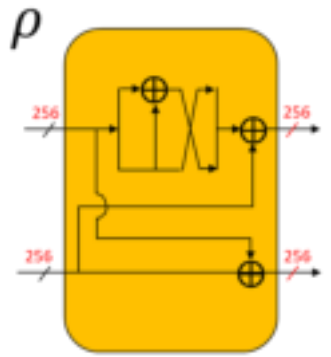



# SPARKLE

- Family of permutation-based AEAD (SCHWAEMM) and hashing (ESCH)
- ARX based design
- Sponge construction with combined feedback
- Tweak to change the primary variant

| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **SCHWAEMM256-128** | 128-bit key/tag, 256-bit nonce |
| | SCHWAEMM128-128 | 128-bit key/nonce/tag |
| | SCHWAEMM192-192 | 192-bit key/nonce/tag |
| | SCHWAEMM256-256 | 256-bit key/nonce/tag |
| Hash | **ESCH256** | 256-bit digest |
| | ESCH384 | 384-bit digest |
| XOF | XOESCH256 | Arbitrary length digest |
| | XOESCH384 | Arbitrary length digest |

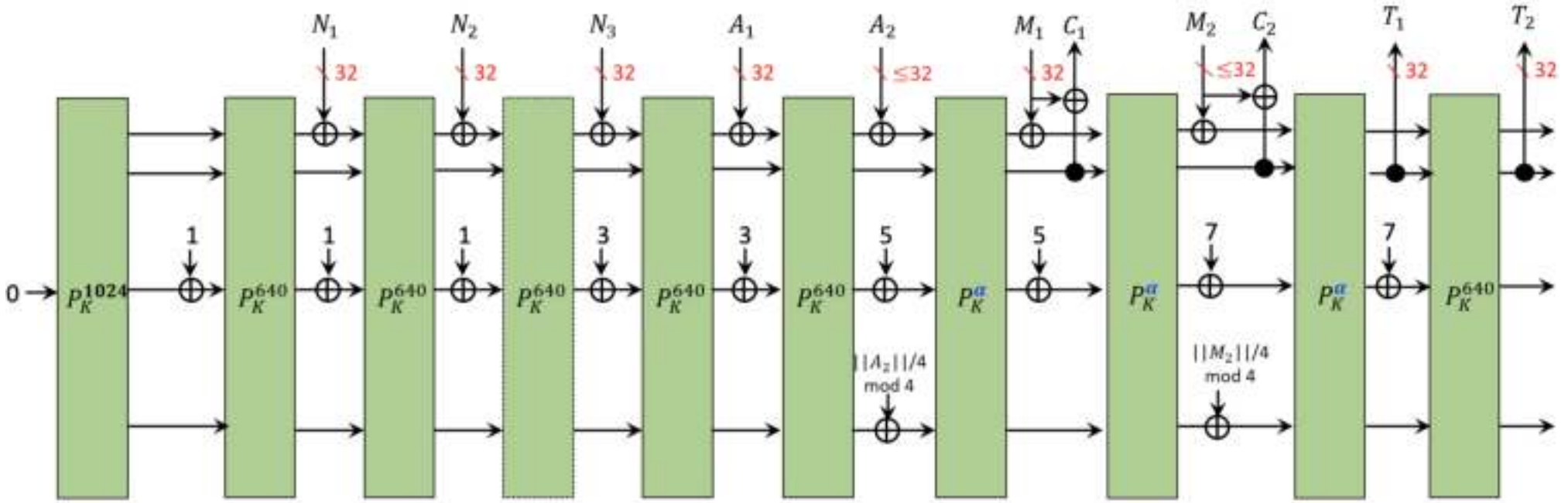


# TINYJAMBU

- Keyed-permutation based AEAD scheme
- Uses 128-bit nonlinear feedback shift register
- Inspired by JAMBU (CAESAR candidate)
- Design tweak: increase in number of rounds to improve security margin.

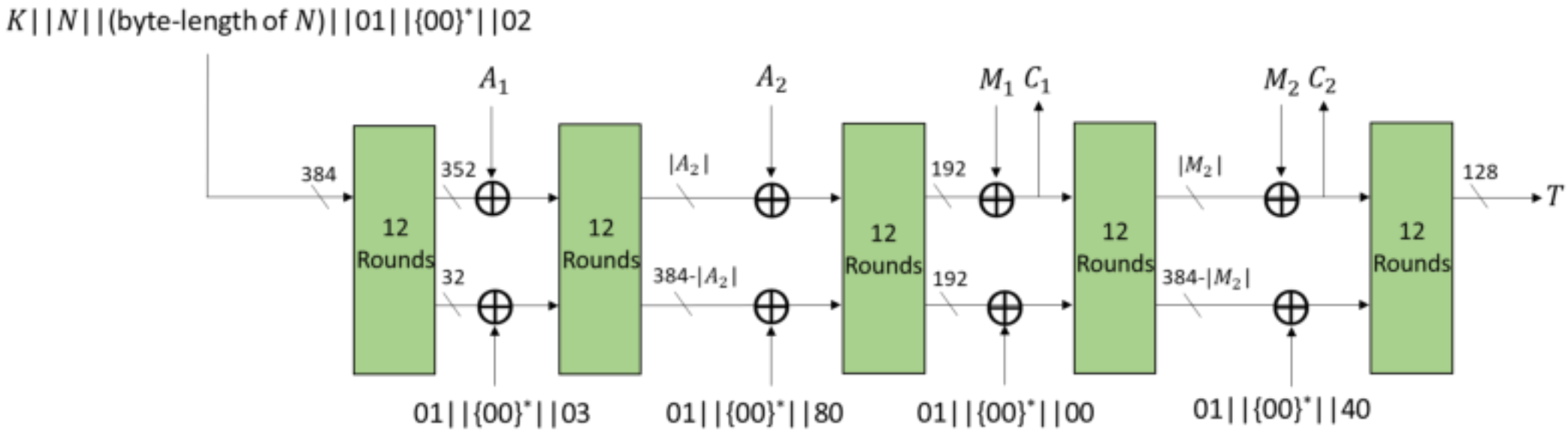
| Variant | Parameter sizes |
|---|---|
| **TinyJambu-128** | 128-bit key, 96-bit nonce, 64-bit tag |
| TinyJambu-192 | 192-bit key, 96-bit nonce, 64-bit tag |
| TinyJambu-256 | 256-bit key, 96-bit nonce, 64-bit tag |



# XOODYAK

- Family of permutation based AEAD & hashing scheme
- Based on 384-bit Xoodoo permutation
- Uses Cyclist mode
- Design tweak: simplified initialization to improve performance for short messages

| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **Xoodyak** | 128-bit key/nonce/tag |
| Hash | **Xoodyak** | 256-bit digest |
| XOF | Xoodyak | Arbitrary length digest |



# Security Margins and Claims

**Security Requirements:** At least 128-bit keys, input message sizes of at least $2^{50}$-1 bytes etc.

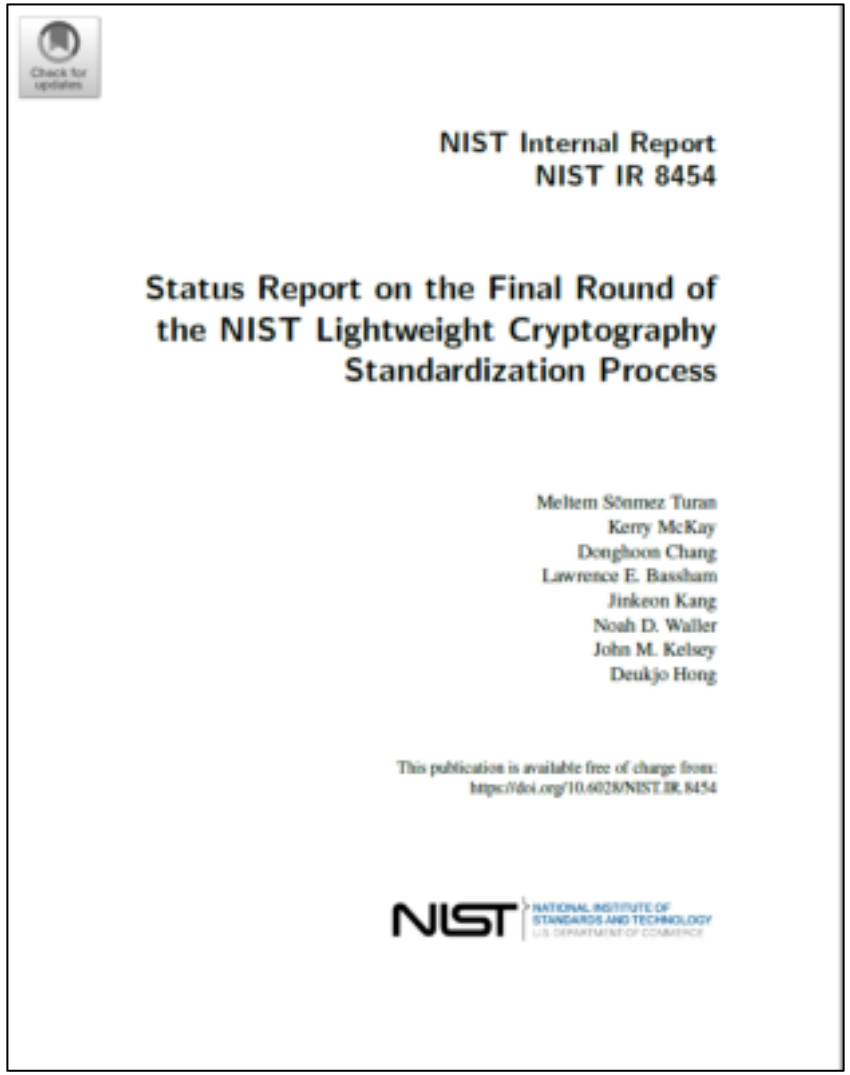
**All finalists have met the security requirements and provided sufficient security margins.**

- None of the security claims made by the submitters have been invalidated.
- Maturity of the design is one of the important security evaluation factors.
    - Is the finalist based on well-established design principles?
    - Did the finalist receive enough third-party analysis?
    - Are there design tweaks that invalidate the earlier security analysis?
    - Are there any additional concerns (e.g., nonce misuse, related-key, RUP security, post quantum)?

# Selection of Ascon

In February 2023, NIST announced the Ascon family as the winner.

- High security margin, large number of third-party analysis (designed in 2014)
- Primary choice for the for lightweight applications in the final CAESAR portfolio (in 2019)
- No design tweaks
- Performance advantages over NIST standards (AES-GCM and SHA-2) in hardware and software
- Implementation and design flexibility
- Mode-level protection mechanism against leakage and lower additional cost for protected implementations
- Support for additional functionalities XOF,  dedicated MAC, in addition to Hash



NIST Internal Report
NIST IR 8454

Status Report on the Final Round of the NIST Lightweight Cryptography Standardization Process

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Noah D. Waller
John M. Kelsey
Deukjo Hong

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# Which variants to standardize?

| | Variant | Parameter sizes |
|---|---|---|
| AEAD | **Ascon-128** | 128-bit key/nonce/tag |
| | Ascon-128a | 128-bit key/nonce/tag |
| | Ascon-80-pq | 160-bit key, 128-bit nonce/tag |
| Hash | **Ascon-hash** | 256-bit digest |
| | Ascon-hasha | 256-bit digest |
| XOF | Ascon-XOF | Arbitrary length digest |
| | Ascon-XOFa | Arbitrary length digest |

**Current tentative decisions:**

- Either Ascon-128 or both Ascon-128 and Ascon-128a
- Do not include Ascon-80pq
- XOF standardization instead of hash functions

# Possible Updates

- Support of shorter tags: 64 and 96-bit tag
- Support for customization strings
- Little endian encoding of inputs for more efficient implementations
- Support for additional functionalities (PRF, MAC, KDF, DRBG etc.)

# NEXT STEPS

- Publication of the draft standards describing the Ascon family (tentative in 2023)
  - Special Publication (SP) series rather than Federal Information Processing Standards (FIPS) (tentative decision)

- Public comments period of 60 to 90 days

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# CONTACT US

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**PUBLIC FORUM** lwc-forum@list.nist.gov

**GITHUB** https://github.com/usnistgov/Lightweight-Cryptography-Benchmarking

**WEBSITE** https://csrc.nist.gov/Projects/lightweight-cryptography