

**NEC Storage Encryption Board for NVMe**

**FIPS 140-2**

**Non-Proprietary Cryptographic Module Security Policy**

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# 1 Introduction

This document defines the Security Policy for the NEC Storage Encryption Board for NVMe, hereafter denoted as the module. The module is 32 Gb/s PCIe I/O module with Encryption. The module provides high speed data at rest encryption for NEC storage. In other words, the module encrypts data onto SSDs and decrypts data read from SSDs using XTS-AES. The XTS-AES mode is approved by CMVP for protecting the confidentiality of data on storage devices. The module meets FIPS 140-2 overall Level 1 requirements.

**Table 1 – Cryptographic Module Configuration**

1	Module	HW P/N and Version	FW Version
	NEC Storage Encryption Board for NVMe	P/N:VSPEBN-001 Version: 001	FPGA Main Firmware Ver : ED00802E FPGA Configuration data Ver : ED000101_20120700* <sup>1</sup> FPGA bootloader Firmware Ver: 00000003

\*1 This version of FPGA Configuration data is NEC Storage Encryption Board for NVMe (Ver 30A9-01).

The module is intended for use by US Federal agencies and other markets that require FIPS 140-2 validated PCIe I/O module used for NEC storage system with data at rest encryption feature. The module is a hardware cryptographic module with multi-chip embedded embodiment.

The FIPS 140-2 security levels for the module are as follows:

**Table 2 – Security Level of Security Requirements**

Security Requirement	Security Level
Cryptographic Module Specification	1
Cryptographic Module Ports and Interfaces	1
Roles, Services, and Authentication	2
Finite State Model	1
Physical Security	1
Operational Environment	N/A
Cryptographic Key Management	1
EMI/EMC	1
Self-Tests	1
Design Assurance	1
Mitigation of Other Attacks	N/A
Overall	1

## 1.1 Hardware and Cryptographic Boundary

The physical form of the module is depicted in Figure 1(a). Black bold line shows the cryptographic boundary. Major components of the module are FPGA, SDRAM, SPI ROM and interfaces. Figure 1(b) is an example of assembling two modules on a circuit board. The module relies on NEC storage as input/output devices.

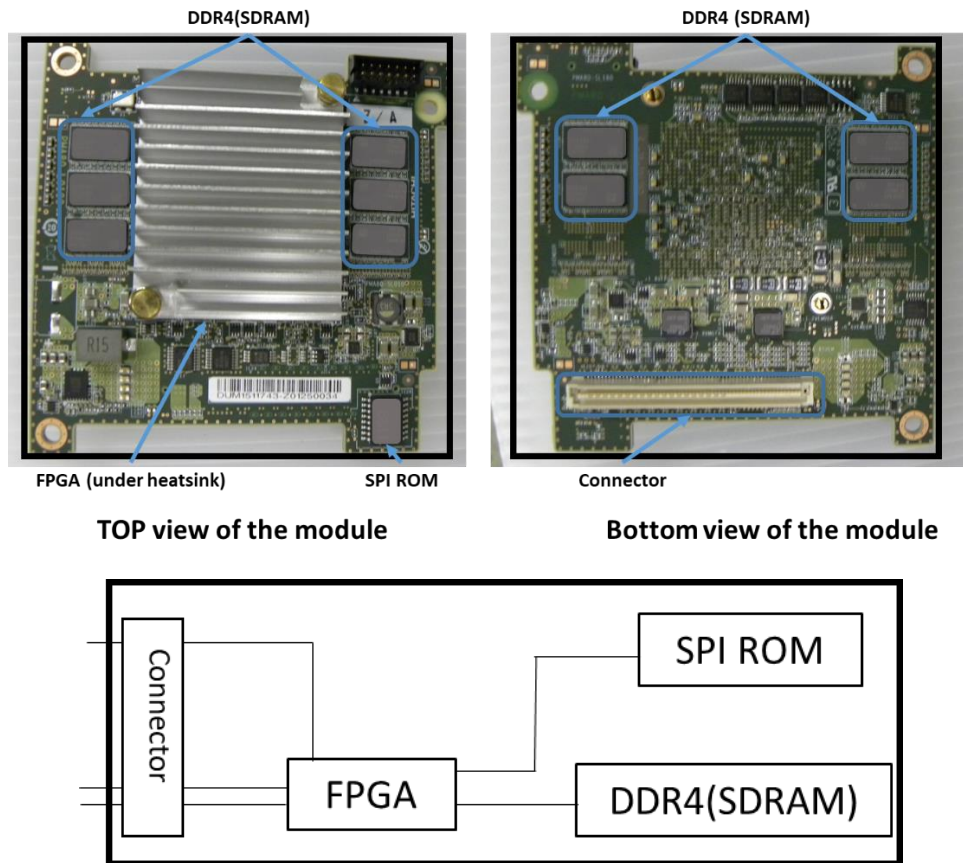
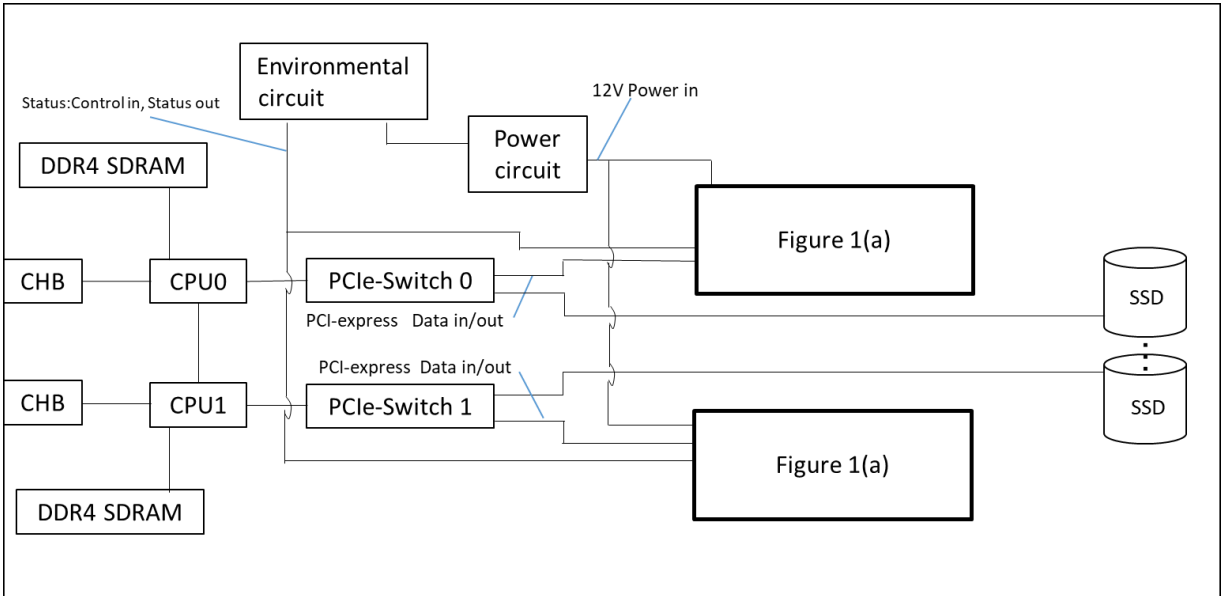


Figure 1(a) – Module Block Diagram on cryptographic boundary

The FPGA is responsible for processing IOs to SSDs as well as encrypting/decrypting IOs where applicable. FPGA as encryption engine implements AES and SHS. Firmware images are stored in the SPI ROM. They are loaded to the FPGA when the module power up. All functions and system initialization are performed by the FPGA, which is contained within the cryptographic boundary of the module. CSPs are stored in SPI ROM or RAM areas of the FPGA.



**Figure 1(b) – Module Block Diagram on overall view**

**Table 3 – Ports and Interfaces**

Port	Description	Logical Interface Type
PCI-express	Plaintext/cipher text input/output Command input	- Data in - Data out - Control in - Status output
MiSC	RST (On demand KATs)	- Control in
Clock	Clock	- Control in
GND	GND	- GND
Power	12V power input	- Power
JTAG	JTAG connection Not to be used in this module	Non-relevant interface

Since the JTAG ports are not permitted to be used in this module, it is not permitted to connect a device to a JTAG connector on the circuit board to which the JTAG ports of the module are wired.

## 1.2 Mode of Operation

The module only supports FIPS-approved mode of operation, and therefore, only supports FIPS-approved security functions. No other modes of operation and no other security functions are implemented.

## 2 Cryptographic Functionality

The module implements the FIPS Approved cryptographic functions listed in the tables below.

The module implements no vendor affirmed security function.

**Table 4 – Approved and CAVP Validated Cryptographic Functions**

Algorithm	Description	Cert #(FPGA Configuration data Ver)
AES-ECB	[FIPS 197] [SP 800-38A] Functions: Encryption, Decryption Key sizes: 256 bits	A1492(ED000101_20120700)
XTS-AES mode	[FIPS 197] [NIST SP 800-38E] Functions: Encryption, Decryption Key sizes: 256 bits	A1492(ED000101_20120700)
AES Key Unwrap (KTS)	[FIPS 197] [NIST SP 800-38F] Functions: Key unwrapping; key establishment methodology provides 256 bits of encryption strength Key sizes: 256 bits	A1492(ED000101_20120700)
SHS	[FIPS 180-4] Functions: Calculation of HMAC, Message digesting of authentication data SHA sizes: SHA-256	A1492(ED000101_20120700)
HMAC	[FIPS 198-1] Functions: MAC generation SHA sizes: SHA-256	A1492 (ED000101_20120700)

The XTS mode is only approved for hardware storage applications.

## 2.1 Critical Security Parameters

All CSPs used by the module are described in this section. All usage of these CSPs by the module (including all CSP lifecycle states) is described in the services detailed in Section 3.

**Table 5 – Critical Security Parameters (CSPs)**

CSP	Description / Usage
Authentication data	256-bit string used to authenticate the operator. This bit string is set initial values as factory-set. Different values are set for each Role, such as User or Crypto Officer. Services other than Operator management cannot be used until initial Authentication Data is updated. Operator Management service zeroizes Authentication data by overwriting with 0xFF(Flash Erase). Authentication data is stored in the SPI ROM in the module.
KEK	256-bit key used to unwrap DEKs and HMAC Keys using AES Key Unwrap. DEKs and HMAC Keys wrapped with KEK using AES Key Wrap are entered to the module . In addition, KEK is used for updating the KEK itself.  KEK Management service zeroizes KEK by overwriting with 0xFF.  The Initial KEK is generated outside the module and is input to the module when the module is manufactured. KEK is stored in the SPI ROM in the module.
DEK	Two 256-bit keys used for XTS-AES encryption/decryption.  DEK Management service zeroizes DEK by overwriting with 0x00.  DEK is stored in the SRAM inside FPGA in the module.
HMAC Key	256-bit key used for authenticating firmware loaded from host .  HMAC Key Management service zeroizes HMAC Key by overwriting with 0xFF.  HMAC Key is stored in the SPI ROM in the module.



### 3 Roles, Authentication and Services

#### 3.1 Assumption of Roles

The module supports two distinct operator roles, User and Cryptographic Officer (CO). The cryptographic module enforces the separation of roles, since concurrent operators are not supported. Re-authentication is enforced when changing roles. An operator is required to log out before another operator can log in, or change a role to another role using an authentication data of another role.

Table 6 lists all operator roles supported by the module. The module does not support a maintenance role and bypass capability. After the module powers off, all the data stored in SDRAM, including previously authenticated operators, are cleared. All CSPs are protected through APIs and logic developed for the sole purpose of integration into specific NEC host platforms. Only NEC-authored drivers can access cryptographic APIs. Further, the module functionally does not allow keys and authentication data to be disclosed, modified, or substituted in FIPS mode of operation.

**Table 6 – Roles Description**

Role ID	Role Description	Authentication Type	Authentication Data
CO	Cryptographic Officer – The role which used to FPGA assumed to perform cryptographic initialization or management functions.	Role-based	256-bit string
User	User – The role assumed to perform general security services, including cryptographic operations and other approved security functions.	Role-based	256-bit string

### 3.2 Authentication Methods

The module enforces role separation by requiring 256-bit authentication data for the two roles: User and Cryptographic Officer. The Authentication data for each role is inputted in plaintext to authenticate the operator when it logs in as the role. The module can login from Cryptographic Officer (User) to User (Cryptographic Officer), and check Authentication data.

The module holds the Authentication data digest to verify whether a digest of inputted Authentication data matches with it or not.

Authentication process requires more than 300ms (actual measured value).

**Table 7 – Authentication Description Strengths**

Authentication Method	Probability of a Single Successful Random Attempt	Probability of a Successful Attempt within a Minute
Credential (authentication data)	$1/2^{256}$ The probability that a random attempt will succeed or a false acceptance will occur depends on 256-bit Authentication data. Therefore, the probability is $1/2^{256}$ , which is less than $1/1,000,000$ .	$200/2^{256}$ Since authentication requires more than 300ms in a worst case scenario, the module can perform at most 200 times Authentication data per minute. Therefore, the probability that multiple attacks within a given minute will be successful is $200/2^{256}$ , which is less than $1/100,000$ .

### 3.3 Services

All services implemented by the module are listed in the tables below. Each service description also describes all usage of CSPs by the service. Also, Table 8 shows the role that is able to perform the service.

**Table 8 – Authenticated Services**

Service	Description	CO	User
Operator Management	Adds an operator's role, and an Authentication data, updates the Authentication data and zeroizes one or all operators and Authentication data Security function: hash function(SHS)	X	X
Logout	Operator logout of the module This service can execute when operator logged in Security function: none	X	X
Decrypt	Decrypts data using XTS-AES Security function: block cipher(XTS-AES)		X
Encrypt	Encrypts data using XTS-AES Security function: block cipher(XTS-AES)		X
DEK Management	Loads, updates and zeroizes DEKs Security function: symmetric key algorithm(AES Key Unwrap)	X	X
KEK Management	Loads, updates and zeroizes KEKs Security function: symmetric key algorithm(AES Key Unwrap)	X	X
HMAC Key Management	Loads, updates and zeroizes the HMAC key Security function: symmetric key algorithm(AES Key Unwrap)	X	X
Firmware Update	Updates the FPGA Main Firmware Security function: message authentication code(HMAC)	X	X
Abort	Abort Decrypt and Encrypt Security function: none		X

Table 9 shows the services that are available without an operator authentication.

**Table 9 – Unauthenticated Services**

Service	Description
On demand power up self-tests	Perform power off/on
On demand KATs	Perform KATs
Login	Authenticates operators
Get Current Operator	Get the operator’s role and an identity string of the current operator
Revert	Zeroizes CSPs, and an Authentication data returns initialization.
Show Status	Show module status with LEDs or bits in a status register Refer to backend NVMe IF specification about bits in a status register as MRPC command
Hardware Setting	Initialize hardware settings
Copy transmission	Copy I/O data, after the module is performed login first time

Table 10 defines the relationship between access to CSPs and the different module services. The modes of access shown in the table are defined as:

- E = Execute: The module executes using the CSP.
- W = Write: The module writes the CSP. The write access is typically performed after a CSP is imported into the module, when the module generates a CSP, or when the module overwrites an existing CSP.
- Z = Zeroize: The module zeroizes the CSP.

**Table 10 – CSP Access Rights within Services**

Service	CSP			
	KEK	DEK	Authentication data	HMAC Key
Operator Management			W/Z	
Decrypt		E		
Encrypt		E		
DEK Management	E	W/Z		
KEK Management	E/W/Z			
HMAC Key Management	E			W/Z
Firmware Update				E
On demand power up self-tests				
On demand KATs				
Hardware setting				
Abort				
Login			E	
Logout				
Get Current Operator				
Show Status				
Revert	Z	Z	Z	Z
Copy transmission				

## 4 Self-tests

Each time the module is powered up it tests that the cryptographic algorithms still operate correctly and that sensitive data have not been damaged. Power up self-tests are available on demand by power cycling.

On power up or reset, the module performs the self-tests described in Table 11 below. Each Firmware Integrity test and all Cryptographic Algorithm Known Answer tests (hereafter KATs) must be completed successfully prior to any other use of cryptography by the module. If Firmware Integrity test or one of the KATs fails, the module enters the error state. If one of the KATs fails, the module shows the result of self-tests with bits in a register status are set as “1b”. If Firmware Integrity test fail, signal path (connected PCIe-Switch to the module) doesn't link up. As a result, the register status is not observable when the Firmware Integrity test is failed, because of the link down of the signal path. Therefore, the link down of the signal path is an indicator for the Firmware Integrity test failure.

Self-tests do not require any intervention or input from the operator. Power up self-tests are automatically executed when the module is powered up. Conditional self-tests are automatically performed when an applicable security function or operation is invoked.

**Table 11 – Power Up Self-tests**

Test Target	Description
Firmware Integrity	16 or 32 bit CRC performed over all code in Flash memory.
XTS-AES mode	KATs: Encryption, Decryption Key size: 256 bits
AES Key Unwrap	KAT: Unwrap Key size: 256 bits
HMAC	KAT: Verification SHA size: SHA-256

Note1: The SHA-256 algorithm doesn't perform independently for self-test, but is performed the self-tests using HMAC ; thus, the SHA-256 doesn't describe Table 11.

Note2: The AES ECB (256bit) algorithm doesn't perform independently for self-test, but is performed the self-tests using XTS-AES ; thus, the AES ECB doesn't describe Table 11.

Note3: Perform 16bit CRC for FPGA Main Firmware

Perform 32bit CRC for FPGA bootloader Firmware and Configuration data

As the FPGA Main Firmware is being externally sent to the module, the firmware images are authenticated using the HMAC authentication technique. Both a loaded firmware image and the HMAC key stored in the module are fed into the SHA engine, together with the proper SHA-256 algorithm, the calculated HMAC digest is compared with the one embedded in the firmware image. If they don't equal, the firmware authentication fails and the module indicate the state. If “Firmware Update” results in failure, the admin status field code of 11XXb is sent from the FPGA as the response.

On demand, the module performs KATs as other conditional self-test. At this time, If one of the KATs fails, the module enters the KATs error state. If one of the KATs fails, the module shows the result of self-tests with bits in a register status are set as “1b”.

**Table 12 – Conditional Self-tests**

Test Target	Description
Firmware Load	HMAC authentication performed when the FPGA Main Firmware is loaded.
Cryptographic algorithms tested by "On demand KATs"	XTS-AES mode    KATs: Encryption, Decryption Key size: 256 bits
	AES Key Unwrap KAT: Unwrap Key size: 256 bits
	HMAC                KAT: Verification SHA size: SHA-256

## 5 Physical Security Policy

The module is a multi-chip embedded cryptographic module and conforms to Level 1 requirements for physical security. The cryptographic module consists of production-grade components.

## 6 Operational Environment

The module is designated as a limited operational environment under the FIPS 140-2 definitions. The module includes a firmware load service to support necessary updates. New firmware versions within the scope of this validation must be validated through the FIPS 140-2 CMVP. Any other firmware loaded into this module is out of the scope of this validation and require a separate FIPS 140-2 validation.

## 7 Mitigation of Other Attacks Policy

The module does not mitigate other attacks.

## 8 Security Rules and Guidance

The module design corresponds to the module security rules. This section documents the security rules enforced by the cryptographic module to implement the security requirements of this FIPS 140-2 Level 1 module. The module does not include two independent implementations of the same cryptographic algorithm.

1. The module shall provide two distinct operator roles: User and Cryptographic Officer.
2. The module shall provide role-based authentication.
3. The module shall clear previous authentications on power cycle.
4. When the module has not been placed in a valid role, the operator shall not have access to any cryptographic services shown in Table 8.
5. The operator shall be capable of commanding the module to perform the power up self-tests by cycling power.
6. Power up self-tests do not require any operator action.
7. Data output shall be inhibited during power up self-tests, zeroization, and error states.
8. Status information does not contain CSPs or sensitive data that if misused could lead to a compromise of the module.
9. There are no restrictions on which keys or CSPs are zeroized by the zeroization service.
10. The module does not support concurrent operators .
11. The module does not support a maintenance interface or role.
12. The module does not support manual key entry.
13. The module does not have any external input/output devices used for entry/output of data.
14. The module does not output plaintext CSPs.

### 8.1 Crypto Officer Guidance

The approved security functions for the CO role is included in Table 8 of the security policy (the services allocated for the "CO" role).

There is no physical port and logical interface dedicated to the CO only.

Since this module is assumed to be delivered to the Crypto Officer as embedded on the main circuit board as shown in Figure (b), the installation procedure is not included in this guidance. Since the JTAG ports are not permitted to be used in this module, it is not permitted to connect a device to a JTAG connector on the circuit board to which the JTAG ports of the module are wired.

The following personalization procedure by which the operator is authenticated upon accessing the module for the first time.

1. Supply power into the module



2. Update or set the authentication data, KEK, DEK and HMAC Key by the following personalization procedures when the module is accessed for the first time.
  - a. Log in as the CO role with the factory setting CO authentication data. Use the Login service.
  - b. Replace a default KEK with a unique KEK. Use the KEK Management service.
  - c. Change the CO and User authentication data. Use the Operator Management service.
  - d. Transfer DEK to FPGA. Use the DEK Management service.
  - e. Transfer HMAC Key to FPGA. Use the HMAC Key Management service.
  - f. Close the Login session. Use the Logout service.

## **8.2 User Guidance**

The approved security functions for the user role is included in Table 8 of the security policy (the services allocated for the "User" role). Refer to Hard Micro IF Specification for the details of the security functions.

There is no physical port and logical interface dedicated to the User only.

The user responsibilities necessary for the secure operation of the module is below.

Since the JTAG ports are not permitted to be used in this module, it is not permitted to connect a device to a JTAG connector on the circuit board to which the JTAG ports of the module are wired.

## **8.3 Firmware Update**

In order to update the FPGA Main Firmware, the Firmware Update service is used. This service is permitted to both CO and User roles. When the Firmware Update command is called, the firmware code for update is loaded and stored to the standby area of the firmware that is on the SPI ROM. After finishing to store the loaded firmware code to the standby area, the loaded firmware is authenticated by the Firmware Load test. If the module passes the test, the standby area in which the loaded firmware is stored is changed to the active area, and the loaded firmware is used in the module after reset. If the module fails the test, the standby area is not changed to the active area, and therefore, the loaded firmware in the standby area is not used.

## **9 Design Assurance Policy**

### **9.1 Configuration Management Overview**

Programs and documents are managed using proprietary web-based configuration management system (Electric Stock System). Documents for validation and hardware components are managed by revision management by proprietary ledger.

### **9.2 Installation, Initialization, and Start-up Overview**

The procedure is described in section 8.1.

## 10 References and Definitions

The following standards are referred to in this Security Policy.

**Table 13 – References**

Abbreviation	Full Specification Name
[FIPS140-2]	<i>Security Requirements for Cryptographic Modules, May 25, 2001</i>
[NIST SP 800-131A]	<i>Transitions: Recommendation for Transitioning the Use of Cryptographic Algorithms and Key Lengths, January 2011</i>
[NIST SP 800-38A]	<i>Recommendation for Block Cipher Modes of Operation Methods and Techniques, 2001 Edition</i>
[FIPS 198-1]	<i>The Keyed-Hash Message Authentication Code(HMAC), July 2008</i>
[NIST SP 800-38E]	<i>Recommendation for Block Cipher Modes of Operation: The XTS-AES Mode for Confidentiality on Storage Devices, January 2010</i>
[NIST SP 800-38F]	<i>Recommendation for Block Cipher Modes of Operation: Methods for Key Wrapping, December 2012</i>
[User Guide]	<i>NEC Virtual Storage Platform E/F series and G series Encryption License Key User Guide, 4060-1J-U05-10, April 2020 (or later)</i>

**Table 14 – Acronyms and Definitions**

Acronym	Definition
AES	Advanced Encryption Standard
CRC	Cyclic Redundancy Check
CSP	Critical Security Parameter
DEK	Data Encryption Key
FIPS	Federal Information Processing Standard
HMAC	Hash-based Message Authentication Code
KAT	Known Answer Test
KEK	Key Encryption Key
NIST	National Institute of Standards and Technology