HALBORN

# StakeWise - Protocol V3

## Smart Contract Security Audit

Prepared by: **Halborn**

Date of Engagement: **April 3rd, 2023 - April 28th, 2023**

Visit: **Halborn.com**

# DOCUMENT REVISION HISTORY

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| 0.1 | Document Creation | 04/03/2023 | Grzegorz Trawinski |
| 0.2 | Document Updates | 04/20/2023 | Grzegorz Trawinski |
| 0.3 | Final Draft | 04/27/2023 | Grzegorz Trawinski |
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| 1.3 | Remediation Plan Review | 05/05/2023 | Gabi Urrutia |

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# EXECUTIVE OVERVIEW

## 1.1 INTRODUCTION

StakeWise made ETH staking effortless by providing resilient infrastructure and yield strategies. StakeWise 's clients can participate in Ethereum's Proof-of-Stake consensus mechanism (staking) and receive ETH rewards in return.

StakeWise engaged Halborn to conduct a security audit on their smart contracts beginning on April 3rd, 2023 and ending on April 28th, 2023 . The security assessment was scoped to the smart contracts provided in the v3-core GitHub repository. Commit hashes and further details can be found in the Scope section of this report.

## 1.2 AUDIT SUMMARY

The team at Halborn was provided 4 weeks for the engagement and assigned 1 full-time security engineer to audit the security of the smart contracts in scope. The security engineer is a blockchain and smart contract security expert with advanced penetration testing and smart contract hacking skills, and deep knowledge of multiple blockchain protocols.

The purpose of the audits is to:

- Identify potential security issues within the smart contracts

In summary, Halborn identified some improvements to reduce the likelihood and impact of risks, which were mostly addressed by StakeWise . The main one is related to the private vault deposit bypass.

On May 4th, 2023, Halborn team received the updated code repository. HAL-01, HAL-03 and HAL-05 findings were addressed and marked as SOLVED. HAL-02 and HAL-04 findings were not resolved and marked as RISK ACCEPTED, as this functionality works as intended along with StakeWise business

rules. Additionally, StakeWise decided to remove the withdraw() and whitelist features.

## 1.3 TEST APPROACH & METHODOLOGY

Halborn performed a combination of manual and automated security testing to balance efficiency, timeliness, practicality, and accuracy in regard to the scope of this audit. While manual testing is recommended to uncover flaws in logic, process, and implementation; automated testing techniques help enhance coverage of the code and can quickly identify items that do not follow the security best practices. The following phases and associated tools were used during the audit:

- Research into architecture and purpose
- Smart contract manual code review and walkthrough
- Manual assessment of use and safety for the critical Solidity variables and functions in scope to identify any arithmetic related vulnerability classes
- Manual testing by custom scripts
- Scanning of solidity files for vulnerabilities, security hot-spots or bugs. (MythX)
- Static Analysis of security for scoped contract, and imported functions. (Slither)
- Testnet analysis (Remix IDE, Foundry)

# 2. RISK METHODOLOGY

Every vulnerability and issue observed by Halborn is ranked based on **two sets** of **Metrics** and a **Severity Coefficient**. This system is inspired by the industry standard Common Vulnerability Scoring System.

The two **Metric sets** are: **Exploitability** and **Impact**. **Exploitability** captures the ease and technical means by which vulnerabilities can be exploited and **Impact** describes the consequences of a successful exploit.

The **Severity Coefficients** is designed to further refine the accuracy of the ranking with two factors: **Reversibility** and **Scope**. These capture the impact of the vulnerability on the environment as well as the number of users and smart contracts affected.

The final score is a value between 0-10 rounded up to 1 decimal place and 10 corresponding to the highest security risk. This provides an objective and accurate rating of the severity of security vulnerabilities in smart contracts.

The system is designed to assist in identifying and prioritizing vulnerabilities based on their level of risk to address the most critical issues in a timely manner.

## 2.1 Exploitability

### Attack Origin (AO):

Captures whether the attack requires compromising a specific account.

### Attack Cost (AC):

Captures the cost of exploiting the vulnerability incurred by the attacker relative to sending a single transaction on the relevant blockchain. Includes but is not limited to financial and computational cost.

### Attack Complexity (AX):

Describes the conditions beyond the attacker's control that must exist in order to exploit the vulnerability. Includes but is not limited to macro situation, available third-party liquidity and regulatory challenges.

### Metrics:

| Exploitability Metric ($m_E$) | Metric Value | Numerical Value |
|---|---|---|
| Attack Origin (AO) | Arbitrary (AO:A)<br>Specific (AO:S) | 1<br>0.2 |
| Attack Cost (AC) | Low (AC:L)<br>Medium (AC:M)<br>High (AC:H) | 1<br>0.67<br>0.33 |
| Attack Complexity (AX) | Low (AX:L)<br>Medium (AX:M)<br>High (AX:H) | 1<br>0.67<br>0.33 |

Exploitability $E$ is calculated using the following formula:

$$E = \prod m_e$$

## 2.2 Impact

### Confidentiality (C):

Measures the impact to the confidentiality of the information resources managed by the contract due to a successfully exploited vulnerability. Confidentiality refers to limiting access to authorized users only.

### Integrity (I):

Measures the impact to integrity of a successfully exploited vulnerability. Integrity refers to the trustworthiness and veracity of data stored and/or processed on-chain. Integrity impact directly affecting Deposit or Yield records is excluded.

### Availability (A):

Measures the impact to the availability of the impacted component resulting from a successfully exploited vulnerability. This metric refers to smart contract features and functionality, not state. Availability impact directly affecting Deposit or Yield is excluded.

### Deposit (D):

Measures the impact to the deposits made to the contract by either users or owners.

### Yield (Y):

Measures the impact to the yield generated by the contract for either users or owners.

Metrics:

| Impact Metric ($m_I$) | Metric Value | Numerical Value |
|---|---|---|
| Confidentiality (C) | None (I:N) | 0 |
| | Low (I:L) | 0.25 |
| | Medium (I:M) | 0.5 |
| | High (I:H) | 0.75 |
| | Critical (I:C) | 1 |
| Integrity (I) | None (I:N) | 0 |
| | Low (I:L) | 0.25 |
| | Medium (I:M) | 0.5 |
| | High (I:H) | 0.75 |
| | Critical (I:C) | 1 |
| Availability (A) | None (A:N) | 0 |
| | Low (A:L) | 0.25 |
| | Medium (A:M) | 0.5 |
| | High (A:H) | 0.75 |
| | Critical | 1 |
| Deposit (D) | None (D:N) | 0 |
| | Low (D:L) | 0.25 |
| | Medium (D:M) | 0.5 |
| | High (D:H) | 0.75 |
| | Critical (D:C) | 1 |
| Yield (Y) | None (Y:N) | 0 |
| | Low (Y:L) | 0.25 |
| | Medium: (Y:M) | 0.5 |
| | High: (Y:H) | 0.75 |
| | Critical (Y:H) | 1 |

Impact $I$ is calculated using the following formula:

$$I = max(m_I) + \frac{\sum m_I - max(m_I)}{4}$$

## 2.3 Severity Coefficient

Reversibility (R):

Describes the share of the exploited vulnerability effects that can be reversed. For upgradeable contracts, assume the contract private key is available.

Scope (S):

Captures whether a vulnerability in one vulnerable contract impacts resources in other contracts.

| Coefficient ($C$) | Coefficient Value | Numerical Value |
|---|---|---|
| Reversibility ($r$) | None (R:N)<br>Partial (R:P)<br>Full (R:F) | 1<br>0.5<br>0.25 |
| Scope ($s$) | Changed (S:C)<br>Unchanged (S:U) | 1.25<br>1 |

Severity Coefficient $C$ is obtained by the following product:

$$C = rs$$

The Vulnerability Severity Score $S$ is obtained by:

$$S = min(10, EIC * 10)$$

The score is rounded up to 1 decimal places.

| Severity | Score Value Range |
|---|---|
| Critical | 9 - 10 |
| High | 7 - 8.9 |
| Medium | 4.5 - 6.9 |
| Low | 2 - 4.4 |
| Informational | 0 - 1.9 |

## 2.4 SCOPE

Code repositories:

1. Project Name

- Repository: v3-core
- Commit ID: 7603afff540c75e4a2d4a26a891dcd2a214c1d6b
- Smart contracts in scope:
  - libraries/ExitQueue.sol
  - vaults/modules/VaultMev.sol
  - vaults/modules/VaultValidators.sol
  - vaults/modules/VaultWhitelist.sol
  - vaults/modules/VaultImmutables.sol
  - vaults/modules/VaultToken.sol
  - vaults/modules/VaultAdmin.sol
  - vaults/modules/VaultEthStaking.sol
  - vaults/modules/VaultFee.sol
  - vaults/modules/VaultVersion.sol
  - vaults/modules/VaultEnterExit.sol
  - vaults/modules/VaultState.sol
  - vaults/VaultsRegistry.sol
  - vaults/ethereum/EthPrivateVault.sol
  - vaults/ethereum/EthVaultFactory.sol
  - vaults/ethereum/EthVault.sol
  - vaults/ethereum/mev/SharedMevEscrow.sol
  - vaults/ethereum/mev/OwnMevEscrow.sol
  - keeper/KeeperValidators.sol
  - keeper/KeeperRewards.sol
  - keeper/Oracles.sol
  - keeper/Keeper.sol
  - base/ERC20Upgradeable.sol
  - base/Multicall.sol
  - base/Versioned.sol
  - interfaces/IOracles.sol
  - interfaces/IVaultWhitelist.sol

- interfaces/IEthVaultFactory.sol
- interfaces/IERC20.sol
- interfaces/IVaultState.sol
- interfaces/IVaultValidators.sol
- interfaces/IMulticall.sol
- interfaces/IERC20Permit.sol
- interfaces/IKeeperRewards.sol
- interfaces/IEthPrivateVault.sol
- interfaces/IVaultAdmin.sol
- interfaces/IVaultFee.sol
- interfaces/ISharedMevEscrow.sol
- interfaces/IVaultImmutables.sol
- interfaces/IKeeperValidators.sol
- interfaces/IVaultEthStaking.sol
- interfaces/IEthValidatorsRegistry.sol
- interfaces/IEthVault.sol
- interfaces/IVaultToken.sol
- interfaces/IVaultsRegistry.sol
- interfaces/IKeeper.sol
- interfaces/IOwnMevEscrow.sol
- interfaces/IVaultMev.sol
- interfaces/IVaultEnterExit.sol
- interfaces/IVaultVersion.sol
- interfaces/IValidatorsRegistry.sol
- interfaces/IVersioned.sol

Out-of-scope:
- third-party libraries and dependencies
- economic attacks

2. Retest (May 4th-5th, 2023)

- Repository: v3-core
- Commit ID:

# 3. ASSESSMENT SUMMARY & FINDINGS OVERVIEW

| CRITICAL | HIGH | MEDIUM | LOW | INFORMATIONAL |
|---|---|---|---|---|
| 0 | 1 | 0 | 3 | 1 |

| SECURITY ANALYSIS | RISK LEVEL | REMEDIATION DATE |
|---|---|---|
| PRIVATE VAULT WHITELIST DEPOSIT BYPASS POSSIBLE | High (7.0) | SOLVED - 05/04/2023 |
| LACK OF EMERGENCY-STOP PATTERN | Low (3.6) | RISK ACCEPTED |
| LACK OF ZERO ADDRESS CHECK FOR RECEIVER | Low (3.4) | SOLVED - 05/04/2023 |
| VAULTADMIN LACKS OWNERSHIP-TRANSFER PATTERN | Low (3.0) | RISK ACCEPTED |
| INCREASEAPPROVE AND DECREASEAPPROVE CAN BE INTRODUCED | Informational (0.0) | SOLVED - 05/04/2023 |

# FINDINGS & TECH DETAILS

## 4.1 (HAL-01) PRIVATE VAULT WHITELIST DEPOSIT BYPASS POSSIBLE - HIGH (7.0)

Description:

The solution allows deploying two types of vaults: EthVault and EthPrivateVault. The EthPrivateVault allows whitelisted participants to deposit only. However, the assessment revealed that a bypass of this limitation exists in the EthPrivateVault contract. Whereas the deposit() and the updateStateAndDeposit() functions are protected, the solution still allows making a deposit with the receive() function. The receive() function uses internal the _deposit() function instead of public deposit() which contains security constraints. Therefore, any account can deposit in the EthPrivateVault. The list of whitelisted participants is carefully created off-chain. Such a group of accounts may pose significant deposit that may ensure profit. This weakness makes the EthPrivateVault main functionality not relevant and may lead to profit share with any staker.

Code Location:

**Listing 1: EthPrivateVault.sol**

```
53   function deposit(
54     address receiver,
55     address referrer
56   ) public payable override(IVaultEthStaking, VaultEthStaking)
↳ returns (uint256 shares) {
57     if (!(whitelistedAccounts[msg.sender] && whitelistedAccounts[
↳ receiver])) revert AccessDenied();
58     return super.deposit(receiver, referrer);
59   }
```

**Listing 2: VaultEthStaking.sol**

```
39 function deposit(
40     address receiver,
41     address referrer
```

```
42    ) public payable virtual override returns (uint256 shares) {
43      return _deposit(receiver, msg.value, referrer);
44    }
45
46    /// @inheritdoc IVaultEthStaking
47    function updateStateAndDeposit(
48      address receiver,
49      address referrer,
50      IKeeperRewards.HarvestParams calldata harvestParams
51    ) public payable virtual override returns (uint256 shares) {
52      updateState(harvestParams);
53      return deposit(receiver, referrer);
54    }
55
56    /**
57     * @dev Function for depositing using fallback function
58     */
59    receive() external payable {
60      _deposit(msg.sender, msg.value, address(0));
61    }
```

Proof of Concept:

1. Deploy the EthPrivateVault vault as an admin.
2. As a non-whitelisted depositor, attempt to deposit any amount of ether by means of deposit() function.
3. Observe that the above transaction reverts with the AccessDenied error.
4. As a non-whitelisted depositor, attempt to deposit any amount of ether by sending the ether directly to the contract.
5. Observe that the above transaction was completed successfully.

```
    ├─ [0] VM::startPrank(0x00000000000000000000000000000000000Dd11)
    │   └─ ← ()
    ├─ [0] VM::expectRevert(AccessDenied())
    │   └─ ← ()
    ├─ [3137] ERC1967Proxy::deposit{value: 100000000000000000}(0x00000000000000000000000000000000000Dd11, 0x0000000000000000000000000000000000000000)
    │   ├─ [2735] EthPrivateVault::deposit(0x00000000000000000000000000000000000Dd11, 0x0000000000000000000000000000000000000000) [delegatecall]
    │   │   └─ ← "AccessDenied()"
    │   └─ ← "AccessDenied()"
    ├─ [44228] ERC1967Proxy::receive{value: 100000000000000000}()
    │   ├─ [43829] EthPrivateVault::receive() [delegatecall]
    │   │   ├─ [7579] ERC1967Proxy::isHarvestRequired(ERC1967Proxy: [0xd6a8b59cd6142658f21af745F30Cb4472d952b3c]) [staticcall]
    │   │   │   ├─ [2681] Keeper::isHarvestRequired(ERC1967Proxy: [0xd6a8b59cd6142658f21af745F30Cb4472d952b3c]) [delegatecall]
    │   │   │   │   └─ ← false
    │   │   │   └─ ← false
    │   │   ├─ emit Transfer(from: 0x0000000000000000000000000000000000000000, to: 0x00000000000000000000000000000000000Dd11, value: 100000000000000000)
    │   │   ├─ emit Deposit(caller: 0x00000000000000000000000000000000000Dd11, owner: 0x00000000000000000000000000000000000Dd11, assets: 100000000000000000, s
hares: 100000000000000000, referrer: 0x0000000000000000000000000000000000000000)
    │   │   └─ ← ()
    │   └─ ← ()
```

The below unit test implements the PoC:

**Listing 3: VaultEthStaking.sol**

```
39      function
↳ test_hal_EthPrivateVault_deposit_via_receive_as_non_whitelisted()
↳ public {
40          vm.startPrank(depositor1);
41
42          vm.expectRevert(IVaultAdmin.AccessDenied.selector);
43          ethPrivateVault.deposit{value: 1 ether}(depositor1,
↳ depositor1);
44
45          (bool success, ) = payable(address(ethPrivateVault)).call{
↳ value: 1 ether}('');
46          if (!success) revert("Call failed.");
47          vm.stopPrank();
48      }
```

BVSS:

**AO:A/AC:L/AX:L/C:C/I:N/A:N/D:N/Y:M/R:P/S:C (7.0)**

Recommendation:

It is recommended to apply checks against whitelist within the `receive()` function for the `EthPrivateVault`.

Remediation Plan:

**SOLVED:** The StakeWise team solved this issue in commit `7f6a034f2eec866771c5276773d97a5696331a3e`: the `receive()` function in the `EthPrivateVault` is now protected with whitelist check.

## 4.2 (HAL-02) LACK OF EMERGENCY-STOP PATTERN - LOW (3.6)

Description:

The current solution does not implement any kind of emergency stop pattern. Such a pattern allows the project team to pause crucial functionalities, while being in the state of emergency, e.g. being under adversary attack. The most prevalent application of the emergency stop pattern is the the OpenZeppelin's Pausable library (or alternatevily PausableUpgradeable.

In this case, if the emergency stop pattern is not implemented, then functions such as deposit(), withdraw(), setRewardsRoot(), enterExitQueue() cannot be temporarily disabled.

BVSS:

**AO:A/AC:L/AX:H/C:N/I:C/A:C/D:C/Y:C/R:P/S:C (3.6)**

Recommendation:

It is recommended to implement emergency stop pattern across the solution.

Remediation Plan:

**RISK ACCEPTED:** The StakeWise team accepted the risk. Vaults will be used by various businesses. It is a business decision that vaults must be permissionless.

## 4.3 (HAL-03) LACK OF ZERO ADDRESS CHECK FOR RECEIVER - LOW (3.4)

Description:

The EthVault allows withdrawing deposits by the means of the withdraw(), redeem() and enterExitQueue() functions. All of these functions take two addresses as input parameters: receiver and owner. The list and order of parameters might be confusing and prone to human errors. E.g. end user may think that if no receiver is provided, the owner is set as receiver. Therefore, a transaction can be triggered that sends ether to the zero address.
In contrary, the deposit() function contains zero address check for to parameter.

Code Location:

**Listing 4: VaultEnterExit.sol**

```
22 /// @inheritdoc IVaultEnterExit
23   function withdraw(
24     uint256 assets,
25     address receiver,
26     address owner
27   ) external override returns (uint256 shares) {
28     // calculate amount of shares to burn
29     shares = _convertToShares(assets, _totalShares, _totalAssets,
↳ Math.Rounding.Up);
30     _withdraw(receiver, owner, assets, shares);
31   }
32
33   /// @inheritdoc IVaultEnterExit
34   function redeem(
35     uint256 shares,
36     address receiver,
37     address owner
38   ) external override returns (uint256 assets) {
39     // calculate amount of assets to burn
40     assets = convertToAssets(shares);
```

```
41      _withdraw(receiver, owner, assets, shares);
42    }
43
44    /// @inheritdoc IVaultEnterExit
45    function enterExitQueue(
46      uint256 shares,
47      address receiver,
48      address owner
49    ) external override returns (uint256 positionCounter) {
50      if (shares == 0) revert InvalidSharesAmount();
51      if (!IKeeperRewards(keeper).isCollateralized(address(this)))
↳ revert NotCollateralized();
52      // SLOAD to memory
53      uint256 _queuedShares = queuedShares;
54
55      // calculate position counter
56      positionCounter = _exitQueue.getSharesCounter() +
↳ _queuedShares;
57
58      // add to the exit requests
59      _exitRequests[keccak256(abi.encode(receiver, positionCounter))
↳ ] = shares;
60
61      // lock tokens in the Vault
62      if (msg.sender != owner) _spendAllowance(owner, msg.sender,
↳ shares);
63      // reverts if owner does not have enough shares
64      balanceOf[owner] -= shares;
65
66      unchecked {
67        // cannot overflow as it is capped with _totalShares
68        queuedShares = SafeCast.toUint96(_queuedShares + shares);
69      }
70
71      emit Transfer(owner, address(this), shares);
72      emit ExitQueueEntered(msg.sender, receiver, owner,
↳ positionCounter, shares);
73    }
```

**Listing 5: VaultEnterExit.sol**

```
166 function _withdraw(address receiver, address owner, uint256 assets
↳ , uint256 shares) internal {
```

```
167     if (IKeeperRewards(keeper).isHarvestRequired(address(this)))
 ↳ revert NotHarvested();
168
169     // reverts in case there are not enough withdrawable assets
170     if (assets > withdrawableAssets()) revert InsufficientAssets()
 ↳ ;
171
172     // reduce allowance
173     if (msg.sender != owner) _spendAllowance(owner, msg.sender,
 ↳ shares);
174
175     // burn shares
176     balanceOf[owner] -= shares;
177
178     // update counters
179     unchecked {
180       // cannot underflow because the sum of all shares can't
 ↳ exceed the _totalShares
181       _totalShares -= SafeCast.toUint128(shares);
182       // cannot underflow because the sum of all assets can't
 ↳ exceed the _totalAssets
183       _totalAssets -= SafeCast.toUint128(assets);
184     }
185
186     // transfer assets to the receiver
187     _transferVaultAssets(receiver, assets);
188
189     emit Transfer(owner, address(0), shares);
190     emit Withdraw(msg.sender, receiver, owner, assets, shares);
191   }
```

BVSS:

**AO:A/AC:L/AX:M/C:N/I:N/A:N/D:M/Y:N/R:N/S:U (3.4)**

Recommendation:

It is recommended to add a zero address check against the receiver parameter in the withdraw(), redeem() and enterExitQueue() functions.

Remediation Plan:

**SOLVED:** The StakeWise team solved this issue in commit `665711457df10c8a4f1e9ff8d3881a52175757c6`: the zero address check against the `receiver` parameter is now added to the `redeem()` and `enterExitQueue()` functions. The `withdraw()` function was removed.

## 4.4 (HAL-04) VAULTADMIN LACKS OWNERSHIP-TRANSFER PATTERN - LOW (3.0)

Description:

The EthVault allows setting an admin account during the vault's deployment. However, the assessment revealed that there is no possibility to update the admin account within the vault. In the case of account hijacking, multiple functionalities get under permanent control of the attacker, including setFeeRecipient(), setOperator(), upgradeToAndCall(), setWhitelister(), setMetadata().
In contrary, the VaultsRegistry and Keeper solutions implement a two-steps ownership-transfer pattern.

BVSS:

**AO:S/AC:L/AX:L/C:N/I:H/A:H/D:M/Y:M/R:N/S:C (3.0)**

Recommendation:

It is recommended to implement a two-step process where the owner nominates an account and the nominated account needs to call an acceptOwnership() function for the transfer of the ownership to fully succeed. This ensures the nominated EOA account is a valid and active account.

Remediation Plan:

**RISK ACCEPTED:** The StakeWise team accepted the risk of this finding. It is a business decision that vault admin privileges are not transferable. In the future, vault admins can verify themselves through social media (e.g., posting the signature of a signed message on Twitter). Users can be affected if they stake to the vault created by one entity and later transferred to another.

## 4.5 (HAL-05) INCREASEAPPROVE AND DECREASEAPPROVE CAN BE INTRODUCED - INFORMATIONAL (0.0)

Description:

The EthVault implements the ERC20Upgradeable standard. To manage allowance, the solution implements both approve() and permit() functions. However, it does not implement non-standard increaseAllowance() and decreaseAllowance() functions. These functions mitigate the possible front-running of approve() function, where someone may use both the old and the new allowance.

BVSS:

**AO:A/AC:L/AX:L/C:N/I:N/A:N/D:N/Y:N/R:F/S:C (0.0)**

Recommendation:

It is recommended to implement non-standard increaseAllowance() and decreaseAllowance() functions within the ERC20Upgradeable contract.

Remediation Plan:

**SOLVED:** The StakeWise team solved this issue in commit 7f6a034f2eec866771c5276773d97a5696331a3e: the ERC20Upgradeable now implements non-standard increaseAllowance() and decreaseAllowance() functions.

# MANUAL TESTING

In the manual testing phase, multiple unit tests were written in the Foundry framework. Various scenarios were simulated depending on the context and tested smart contract.

The purpose of OwnMevEscrow and SharedMevEscrow unit testing was to verify if the contract's business logic works as expected along with the implemented authorization.

```
Running 11 tests for test/HalbornEscrowTest.t.sol:HalbornEscrowTest
[PASS] test_hal_OwnMevEscrow_harvest_as_non_vault_reverts() (gas: 147613)
[PASS] test_hal_OwnMevEscrow_harvest_balance() (gas: 329642)
[PASS] test_hal_OwnMevEscrow_harvest_balance_as_non_IVaultEthStaking_reverts() (gas: 155764)
[PASS] test_hal_OwnMevEscrow_harvest_zero() (gas: 145240)
[PASS] test_hal_OwnMevEscrow_transfer_ether_to_mev() (gas: 154318)
[PASS] test_hal_SharedMevEscrow_harvest_above_balance_reverts() (gas: 340482)
[PASS] test_hal_SharedMevEscrow_harvest_as_non_vault_reverts() (gas: 157193)
[PASS] test_hal_SharedMevEscrow_harvest_balance() (gas: 340254)
[PASS] test_hal_SharedMevEscrow_harvest_half_of_balance() (gas: 340254)
[PASS] test_hal_SharedMevEscrow_harvest_zero() (gas: 324174)
[PASS] test_hal_SharedMevEscrow_transfer_ether_to_mev() (gas: 163899)
Test result: ok. 11 passed; 0 failed; finished in 6.71ms
```

The purpose of EthPrivateVault unit testing was to verify if contract business logic works as expected along with the implemented authorization. An attempt to bypass the white-list was implemented. Additionally, a scenario was identified where a user can call joinWhitelist() multiple times to add himself/herself to the list after delisting. However, the StakeWise team confirmed that it is not considered as an issue.

```
Running 20 tests for test/HalbornEthPrivateVaultTest.t.sol:HalbornEthPrivateVaultTest
[PASS] test_hal_EthPrivateVault_attempt_to_initilize_twice_reverts() (gas: 26313)
[PASS] test_hal_EthPrivateVault_deposit_as_non_whitelisted() (gas: 143277)
[PASS] test_hal_EthPrivateVault_deposit_as_owner_valid_scenario() (gas: 188827)
[PASS] test_hal_EthPrivateVault_deposit_as_owner_with_empty_receiver_reverts() (gas: 145570)
[PASS] test_hal_EthPrivateVault_deposit_as_owner_with_empty_referrer_valid_scenario() (gas: 188802)
[PASS] test_hal_EthPrivateVault_deposit_valid_scenario() (gas: 71588)
[PASS] test_hal_EthPrivateVault_deposit_via_receive_as_non_whitelisted_valid_scenario() (gas: 185644)
[PASS] test_hal_EthPrivateVault_deposit_via_receive_as_owner_valid_scenario() (gas: 185635)
[PASS] test_hal_EthPrivateVault_joinWhitelist_for_multiple_addresses_valid_scenario() (gas: 685984)
[PASS] test_hal_EthPrivateVault_joinWhitelist_for_one_address_then_updateWhitelist_with_false_then_joinWhitelist() (gas: 90184)
[PASS] test_hal_EthPrivateVault_joinWhitelist_for_one_address_valid_scenario() (gas: 76107)
[PASS] test_hal_EthPrivateVault_joinWhitelist_twice_in_a_row_reverts() (gas: 587690)
[PASS] test_hal_EthPrivateVault_setWhitelistRoot_as_non_admin() (gas: 90959)
[PASS] test_hal_EthPrivateVault_setWhitelister_as_non_admin() (gas: 58574)
[PASS] test_hal_EthPrivateVault_setWhitelister_twice_valid_scenario() (gas: 72599)
[PASS] test_hal_EthPrivateVault_setWhitelister_valid_scenario() (gas: 68350)
[PASS] test_hal_EthPrivateVault_updateWhitelist_as_non_admin() (gas: 90894)
[PASS] test_hal_EthPrivateVault_updateWhitelist_non_existing_to_false_reverts() (gas: 29686)
[PASS] test_hal_EthPrivateVault_updateWhitelist_twice_reverts() (gas: 55313)
[PASS] test_hal_EthPrivateVault_updateWhitelist_valid_scenario() (gas: 42708)
Test result: ok. 20 passed; 0 failed; finished in 9.36ms
```

The purpose of EthVaultFactory unit testing was to verify if contract business logic works as expected.

```
Running 7 tests for test/HalbornEthVaultFactoryTest.t.sol:HalbornEthVaultFactoryTest
[PASS] test_hal_EthVaultFactory_compare_computeAddresses_for_the_same_deployer() (gas: 17946)
[PASS] test_hal_EthVaultFactory_compare_computeAddresses_for_two_deployers() (gas: 21925)
[PASS] test_hal_EthVaultFactory_compare_computeAddresses_for_two_deployers_and_private_vault() (gas: 22009)
[PASS] test_hal_EthVaultFactory_deploy_and_compare_computeAddresses() (gas: 459649)
[PASS] test_hal_EthVaultFactory_deploy_too_high_feePrecent_reverts() (gas: 272206)
[PASS] test_hal_EthVaultFactory_deploy_too_low_security_deposit_reverts() (gas: 355624)
[PASS] test_hal_EthVaultFactory_deploy_too_small_capacity_reverts() (gas: 307104)
Test result: ok. 7 passed; 0 failed; finished in 10.33ms
```

The purpose of MultiCall unit testing was to verify if contract business logic works as expected.

```
Running 3 tests for test/HalbornMultiCallTest.t.sol:HalbornMultiCallTest
[PASS] test_hal_multicall_poc_1_approve_transfer() (gas: 338250)
[PASS] test_hal_multicall_poc_2_empty_deposit_possible() (gas: 257876)
[PASS] test_hal_multicall_poc_3_redeem_twice() (gas: 448591)
Test result: ok. 3 passed; 0 failed; finished in 10.88ms
```

The purpose of EthVault unit testing was to verify if contract business logic works as expected along with the implemented authorization. This part of the unit test included multiple various functionalities from vault's modules, that were excluded in other tests. The upgradability functionality was also included.

```
Running 24 tests for test/HalbornEthVaultTest.t.sol:HalbornEthVaultTest
[PASS] test_hal_EthVault_attempt_to_initilize_twice_reverts() (gas: 26290)
[PASS] test_hal_EthVault_receiveFromMevEscrow_as_non_mev_reverts() (gas: 25720)
[PASS] test_hal_EthVault_setFeeRecipient_as_non_owner_reverts() (gas: 18535)
[PASS] test_hal_EthVault_setFeeRecipient_as_zero_address_reverts() (gas: 29150)
[PASS] test_hal_EthVault_setFeeRecipient_valid_scenario() (gas: 37328)
[PASS] test_hal_EthVault_setMetadata_as_admin() (gas: 20402)
[PASS] test_hal_EthVault_setMetadata_as_non_admin_reverts() (gas: 18773)
[PASS] test_hal_EthVault_setOperator_as_not_an_owner_reverts() (gas: 18514)
[PASS] test_hal_EthVault_setOperator_as_owner_valid_scenario() (gas: 43876)
[PASS] test_hal_EthVault_setOperator_as_zero_address_reverts() (gas: 18562)
[PASS] test_hal_EthVault_setOperator_then_setOperator_back_to_owner() (gas: 52326)
[PASS] test_hal_EthVault_setOperator_then_setOperator_to_zero_address_reverts() (gas: 47596)
[PASS] test_hal_EthVault_setValidatorsRoot_as_not_an_owner_reverts() (gas: 20643)
[PASS] test_hal_EthVault_setValidatorsRoot_twice_valid_scenario() (gas: 27446)
[PASS] test_hal_EthVault_setValidatorsRoot_valid_scenario() (gas: 24141)
[PASS] test_hal_EthVault_upgradeToAndCall_incorrect_vaultId_reverts() (gas: 95211)
[PASS] test_hal_EthVault_upgradeToAndCall_initialize_twice_reverts() (gas: 4191791)
[PASS] test_hal_EthVault_upgradeToAndCall_no_implementation_added_to_registry_reverts() (gas: 4103899)
[PASS] test_hal_EthVault_upgradeToAndCall_the_same_implementation_reverts() (gas: 42126)
[PASS] test_hal_EthVault_upgradeToAndCall_valid_scenario() (gas: 4206520)
[PASS] test_hal_EthVault_upgradeToAndCall_zero_address_not_as_admin_reverts() (gas: 36189)
[PASS] test_hal_EthVault_upgradeToAndCall_zero_address_reverts() (gas: 36219)
[PASS] test_hal_EthVault_upgradeTo_zero_address_not_as_admin_reverts() (gas: 33518)
[PASS] test_hal_EthVault_upgradeTo_zero_address_reverts() (gas: 33502)
Test result: ok. 24 passed; 0 failed; finished in 11.42ms
```

The purpose of Oracles unit testing was to verify if contracts business logic works as expected along with the implemented authorization. Multiple use cases were written to verify if a list of oracles can be properly maintained.

```
Running 14 tests for test/HalbornOraclesTest.t.sol:HalbornOraclesTest
[PASS] test_hal_Oracles_addOracle_as_not_owner() (gas: 11613)
[PASS] test_hal_Oracles_addOracle_as_owner() (gas: 43557)
[PASS] test_hal_Oracles_addOracle_same_address_twice_as_owner() (gas: 45817)
[PASS] test_hal_Oracles_addOracle_then_removeOracle_as_owner() (gas: 35781)
[PASS] test_hal_Oracles_removeOracle_as_not_owner() (gas: 11622)
[PASS] test_hal_Oracles_removeOracle_for_all_oracles_as_owner() (gas: 112855)
[PASS] test_hal_Oracles_removeOracle_for_more_than_requiredOracles_as_owner() (gas: 77949)
[PASS] test_hal_Oracles_removeOracle_for_ten_oracles_as_owner() (gas: 106137)
[PASS] test_hal_Oracles_removeOracle_non_existing_as_owner() (gas: 19659)
[PASS] test_hal_Oracles_setRequiredOracles_as_not_owner() (gas: 13867)
[PASS] test_hal_Oracles_setRequiredOracles_as_owner() (gas: 22599)
[PASS] test_hal_Oracles_setRequiredOracles_as_zero_owner() (gas: 16052)
[PASS] test_hal_Oracles_setRequiredOracles_for_more_than_totalOracles_as_owner() (gas: 19080)
[PASS] test_hal_Oracles_setRequiredOracles_for_totalOracles_as_owner() (gas: 24122)
Test result: ok. 14 passed; 0 failed; finished in 7.95ms
```

In the fallowing unit testing exercise, multiple scenarios were written to verify if deposit and withdraw/redeem functionalities work as expected. The accounting of shares and assets were checked manually.

```
Running 15 tests for test/HalbornDepositTest.t.sol:HalbornDepositTest
[PASS] test_hal_deposit() (gas: 269662)
[PASS] test_hal_deposit_max() (gas: 283331)
[PASS] test_hal_deposit_multiple_deposits() (gas: 338289)
[PASS] test_hal_deposit_one() (gas: 269708)
[PASS] test_hal_deposit_receiver_is_zero_address() (gas: 246263)
[PASS] test_hal_deposit_referrer_as_depositor() (gas: 269664)
[PASS] test_hal_deposit_then_redeem() (gas: 419564)
[PASS] test_hal_deposit_then_redeem_balance_minus_one() (gas: 443786)
[PASS] test_hal_deposit_then_redeem_one() (gas: 442288)
[PASS] test_hal_deposit_then_redeem_to_zero_address() (gas: 447059)
[PASS] test_hal_deposit_then_withdraw() (gas: 419550)
[PASS] test_hal_deposit_then_withdraw_balance_minus_one() (gas: 443805)
[PASS] test_hal_deposit_then_withdraw_one() (gas: 442249)
[PASS] test_hal_deposit_then_withdraw_to_zero_address() (gas: 447020)
[PASS] test_hal_deposit_zero_deposit_is_possible() (gas: 239946)
Test result: ok. 15 passed; 0 failed; finished in 23.13ms
```

The purpose of VaultsRegistry unit testing was to verify if contract business logic works as expected along with the implemented authorization.

```
Running 15 tests for test/HalbornVaultsRegistryTest.t.sol:HalbornVaultsRegistryTest
[PASS] test_hal_addFactory_as_not_an_owner_reverts() (gas: 13564)
[PASS] test_hal_addFactory_as_owner() (gas: 36219)
[PASS] test_hal_addFactory_as_owner_twice_reverts() (gas: 37902)
[PASS] test_hal_addFactory_then_addVault() (gas: 63853)
[PASS] test_hal_addFactory_then_addVault_twice() (gas: 66638)
[PASS] test_hal_addFactory_then_removeFactory_as_owner() (gas: 26876)
[PASS] test_hal_addFactory_then_removeFactory_twice_as_owner_reverts() (gas: 28248)
[PASS] test_hal_addVaultImpl_as_not_an_owner_reverts() (gas: 13519)
[PASS] test_hal_addVaultImpl_as_owner() (gas: 36274)
[PASS] test_hal_addVaultImpl_as_owner_twice_reverts() (gas: 37899)
[PASS] test_hal_addVaultImpl_then_removeVaultImpl_as_owner() (gas: 26895)
[PASS] test_hal_addVaultImpl_then_removeVaultImpl_twice_as_owner_reverts() (gas: 28168)
[PASS] test_hal_addVault_reverts() (gas: 13143)
[PASS] test_hal_removeFactory_as_not_an_owner_reverts() (gas: 13578)
[PASS] test_hal_removeVaultImpl_as_not_an_owner_reverts() (gas: 13565)
Test result: ok. 15 passed; 0 failed; finished in 24.13ms
```

The purpose of Keeper unit testing was to verify if contract business logic works as expected along with the implemented authorization. The upgradability functionality was also included. Various scenarios related to signature handling were also included.

```
Running 15 tests for test/HalbornKeeperTest.t.sol:HalbornKeeperTest
[PASS] test_hal_KeeperRewards_attempt_to_initilize_twice_reverts() (gas: 19706)
[PASS] test_hal_KeeperRewards_initialize_twice_reverts() (gas: 19127)
[PASS] test_hal_KeeperRewards_setRewardsDelay_as_non_owner_reverts() (gas: 18584)
[PASS] test_hal_KeeperRewards_setRewardsDelay_as_owner_to_one_day() (gas: 30636)
[PASS] test_hal_KeeperRewards_setRewardsDelay_as_owner_to_zero() (gas: 30646)
[PASS] test_hal_Keeper_upgradeToAndCall_v2mock_valid_scenario() (gas: 2199983)
[PASS] test_hal_Keeper_upgradeToAndCall_zero_address_not_as_admin_reverts() (gas: 27182)
[PASS] test_hal_Keeper_upgradeToAndCall_zero_address_reverts() (gas: 31980)
[PASS] test_hal_Keeper_upgradeTo_v2mock_valid_scenario() (gas: 2177392)
[PASS] test_hal_Keeper_upgradeTo_zero_address_not_as_admin_reverts() (gas: 26782)
[PASS] test_hal_Keeper_upgradeTo_zero_address_reverts() (gas: 31705)
[PASS] test_hal_updateExitSignatures_twice_reverts() (gas: 662011)
[PASS] test_hal_updateExitSignatures_twice_with_new_nonce() (gas: 745289)
[PASS] test_hal_updateExitSignatures_valid_scenario() (gas: 647610)
[PASS] test_hal_updateExitSignatures_without_validator_registered_reverts() (gas: 326048)
Test result: ok. 15 passed; 0 failed; finished in 72.36s
```

In the fallowing unit testing exercise, multiple scenarios were written to verify if:

- Oracles signature verification works as expected,
- validator registration works as expected,
- multiple validator registration works as expected,
- set rewards root works as expected,
- state update, harvest and state update and deposit work as expected,
- the accounting related to ExitQueue works as expected,
- the accounting differences between standard withdrawal and claim assets

from ExitQueue exists,
- the possibility to overwrite the ExitQueue records exists,
- the accounting in case of profit and loss works as expected.

Additionally, a scenario was identified where harvest reverts due to integer underflow. Whenever a subsequent call to harvest has set a smaller mev reward, this issue occurs. However, the StakeWise team confirmed that it is not considered as an issue as HarvestParams are strictly controlled off-chain and subsequent call cannot have smaller mev reward compared to previous.

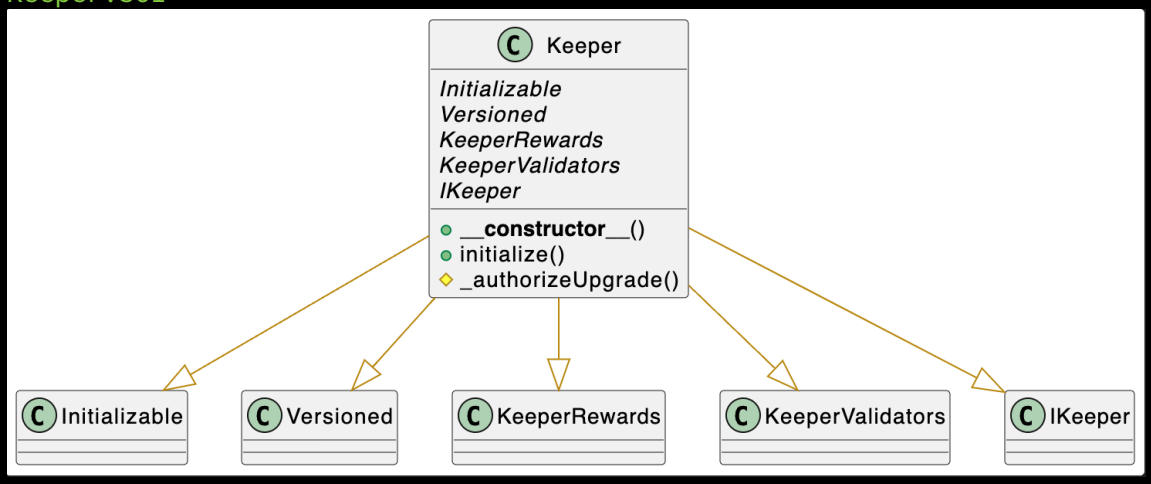
```
Running 44 tests for test/HalbornValidatorTest.t.sol:HalbornValidatorTest
[PASS] test_hal_ValidatorsRegistry_get_deposit_root() (gas: 105201)
[PASS] test_hal_oracles_verifyAllSignatures_all_duplicated_signatures_reverts() (gas: 244630)
[PASS] test_hal_oracles_verifyAllSignatures_empty_exitSignaturesIpfsHash_reverts() (gas: 235566)
[PASS] test_hal_oracles_verifyAllSignatures_incorrect_depositRoot_reverts() (gas: 234918)
[PASS] test_hal_oracles_verifyAllSignatures_incorrect_validators_data_revert() (gas: 234300)
[PASS] test_hal_oracles_verifyAllSignatures_incorrect_vault_address_reverts() (gas: 233915)
[PASS] test_hal_oracles_verifyAllSignatures_last_signature_duplicated_reverts() (gas: 297331)
[PASS] test_hal_oracles_verifyAllSignatures_only_one_signature_reverts() (gas: 225577)
[PASS] test_hal_oracles_verifyAllSignatures_signatures_incorrect_order_reverts() (gas: 272910)
[PASS] test_hal_oracles_verifyAllSignatures_signatures_not_long_enough_reverts() (gas: 229154)
[PASS] test_hal_oracles_verifyAllSignatures_six_signatures_reverts() (gas: 226769)
[PASS] test_hal_oracles_verifyAllSignatures_valid_scenario() (gas: 294373)
[PASS] test_hal_registerValidator_attempt_to_register_twice_reverts() (gas: 972052)
[PASS] test_hal_registerValidator_invalid_proof_reverts() (gas: 842330)
[PASS] test_hal_registerValidator_not_enough_deposit_reverts() (gas: 837138)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_claimExitedAssets_valid_scenario() (gas: 1763288)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_100_ether_then_claimExitedAssets_valid_scenario() (gas: 2640502)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_attempt_to_override_queue() (gas: 2908970)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_but_reverse_order_valid_scenario() (gas: 2640764)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_then_deposit_valid_scenario() (gas: 2856781)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_valid_scenario() (gas: 2631871)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_withdraw_versus_claimExited() (gas: 3069577)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_then_claimExitedAssets_withdraw_versus_claimExited_but_withdraw_withdrawableAssets_before() (gas: 2901874)
[PASS] test_hal_registerValidator_then_enterExitQueue_then_updateState_with_loss_then_claimExitedAssets_valid_scenario() (gas: 2607630)
[PASS] test_hal_registerValidator_then_enterExitQueue_valid_scenario() (gas: 1377319)
[PASS] test_hal_registerValidator_then_setRewardsRoot_quadrice_various_but_fourth_as_first() (gas: 2279489)
[PASS] test_hal_registerValidator_then_setRewardsRoot_then_deposit() (gas: 1494989)
[PASS] test_hal_registerValidator_then_setRewardsRoot_then_harvest_then_enterExitQueue_valid_scenario() (gas: 1181476)
[FAIL. Reason: Arithmetic over/underflow] test_hal_registerValidator_then_setRewardsRoot_then_harvest_then_setRewardsRoot_then_harvest_integer_underflow_reverts() (gas: 1888821)
[PASS] test_hal_registerValidator_then_setRewardsRoot_then_harvest_twice() (gas: 1722302)
[PASS] test_hal_registerValidator_then_setRewardsRoot_then_harvest_valid_scenario() (gas: 1718481)
[PASS] test_hal_registerValidator_then_setRewardsRoot_then_updateStateAndDeposit_valid_scenario() (gas: 1753828)
[PASS] test_hal_registerValidator_then_setRewardsRoot_twice_the_same_rewardTreeRoot_reverts() (gas: 1323466)
[PASS] test_hal_registerValidator_then_setRewardsRoot_twice_various() (gas: 1437551)
[PASS] test_hal_registerValidator_then_setRewardsRoot_twice_various_then_deposit_reverts() (gas: 1815005)
[PASS] test_hal_registerValidator_then_setRewardsRoot_valid_scenario() (gas: 1276039)
[PASS] test_hal_registerValidator_then_updateState_with_loss_then_withdraw_valid_scenario() (gas: 2125755)
[PASS] test_hal_registerValidator_valid_scenario() (gas: 927762)
[PASS] test_hal_registerValidator_valid_scenario_then_setRewardsRoot_too_early_reverts() (gas: 1219506)
[PASS] test_hal_registerValidators_ten_incorrect_indexes_revert() (gas: 1209609)
[PASS] test_hal_registerValidators_ten_incorrect_proofFlags_revert() (gas: 1202423)
[PASS] test_hal_registerValidators_ten_incorrect_validators_revert() (gas: 1197345)
[PASS] test_hal_registerValidators_ten_not_enough_deposit_reverts() (gas: 991955)
[PASS] test_hal_registerValidators_ten_valid_scenario() (gas: 1406599)
Test result: FAILED. 43 passed; 1 failed; finished in 88.08s
```

# CONTRACT UPGRADABILITY

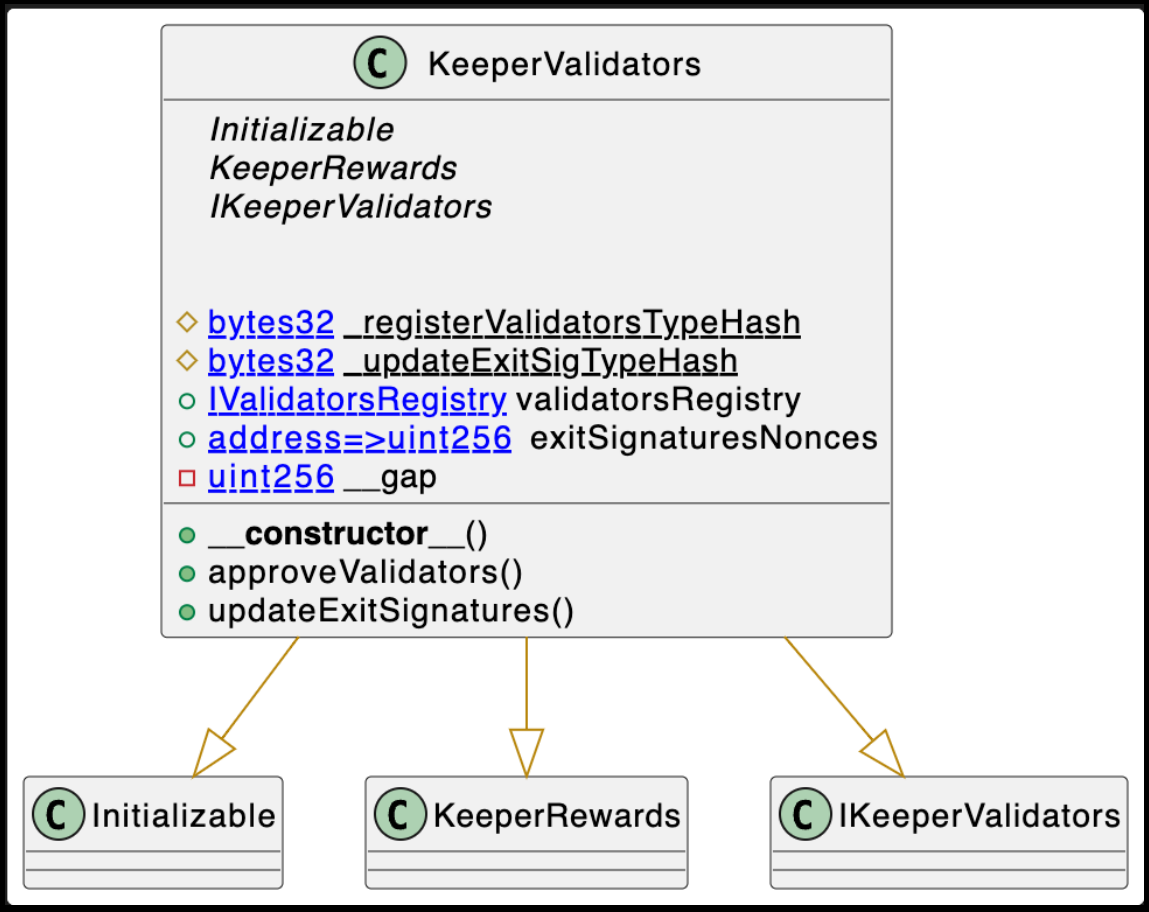
## 6.1 Solution Structure

The team at Halborn analyzed the structure of the smart contracts in scope to make sure all future upgrades are secure. The StakeWise team decided to use the ERC1967Proxy and UUPSUpgradeable within the solution. The EthVault, EthPrivateVault and Keeper contracts implement the UUPSUpgradeable. The EthVaultFactory contract uses ERC1967Proxy for deploying the vaults' implementations.

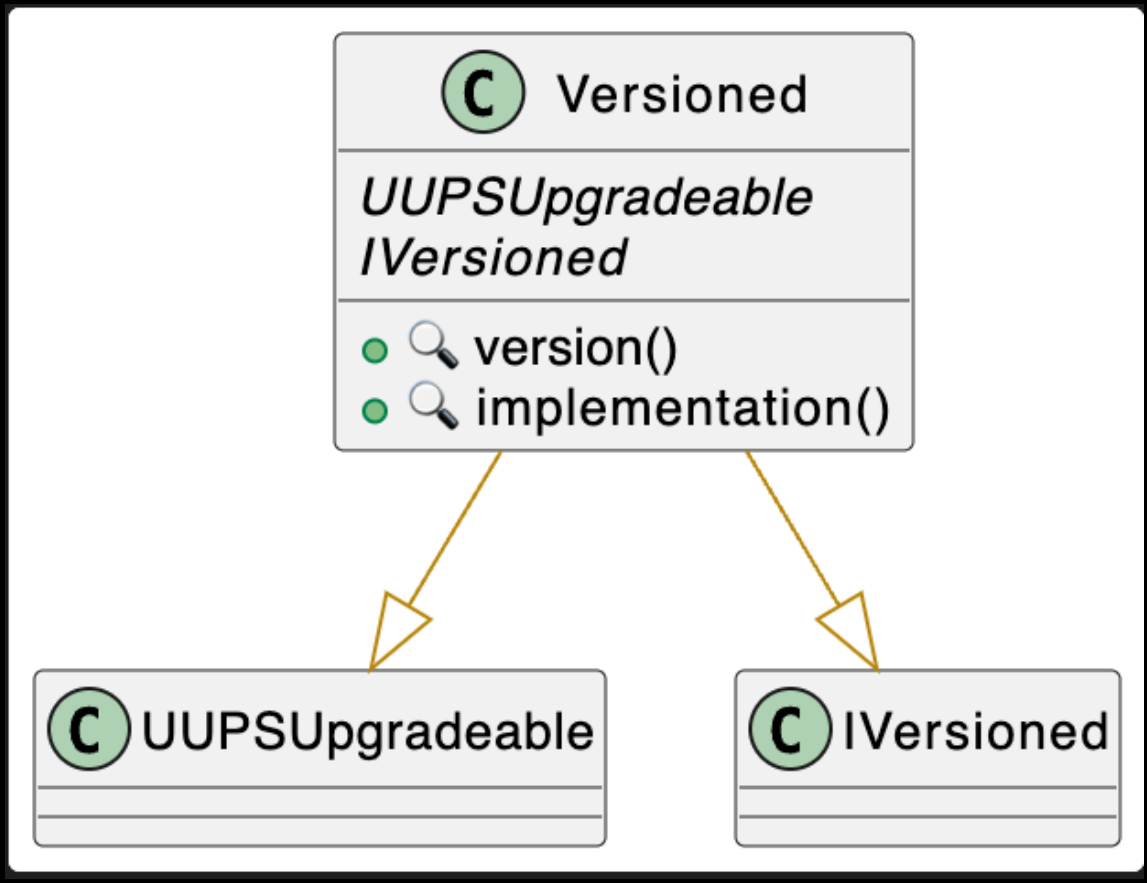
Keeper.sol



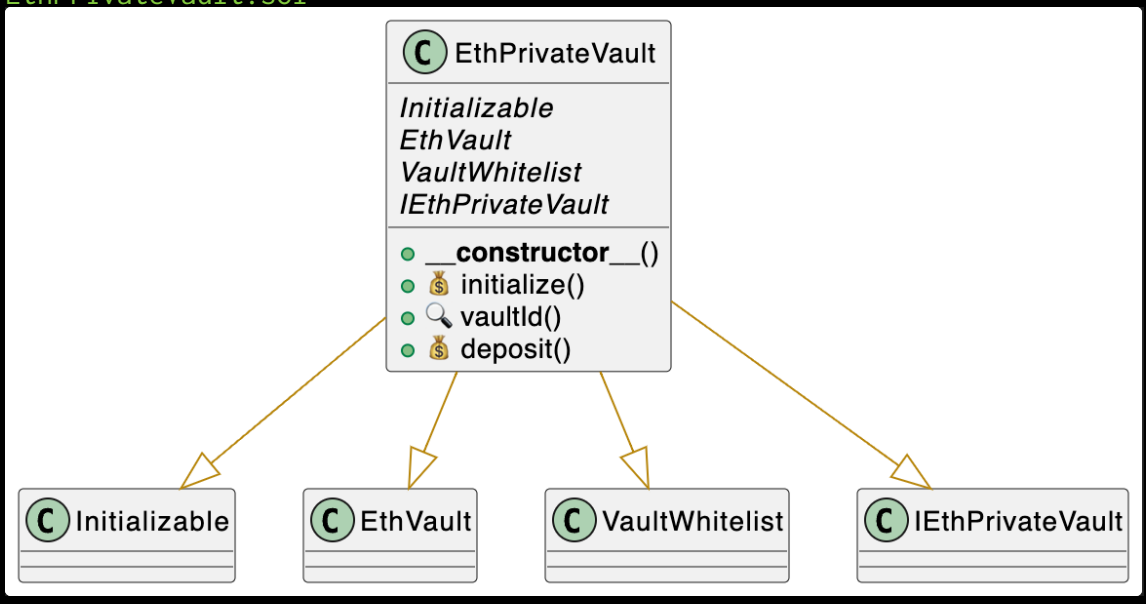
# CONTRACT UPGRADABILITY



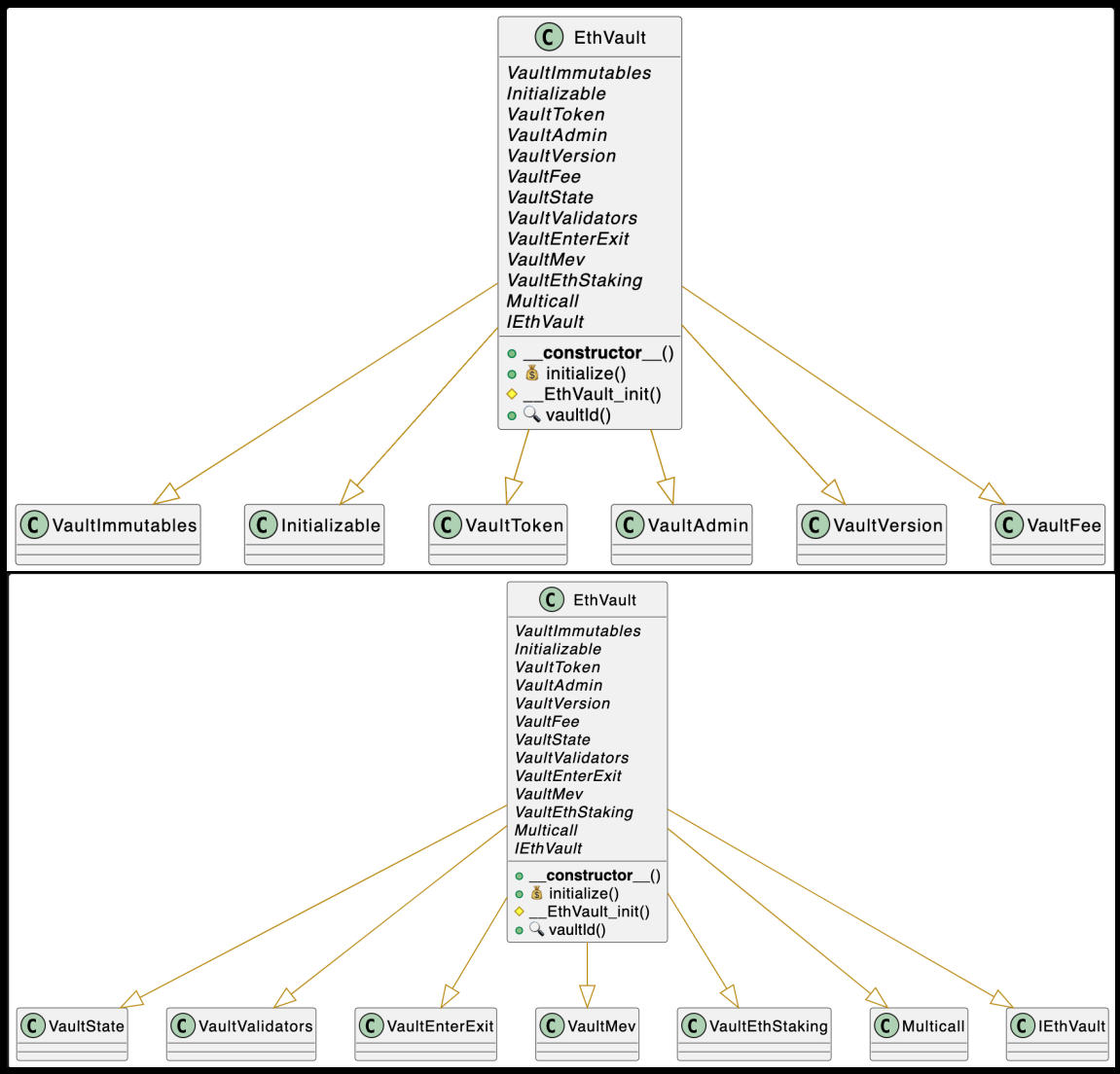
# CONTRACT UPGRADABILITY

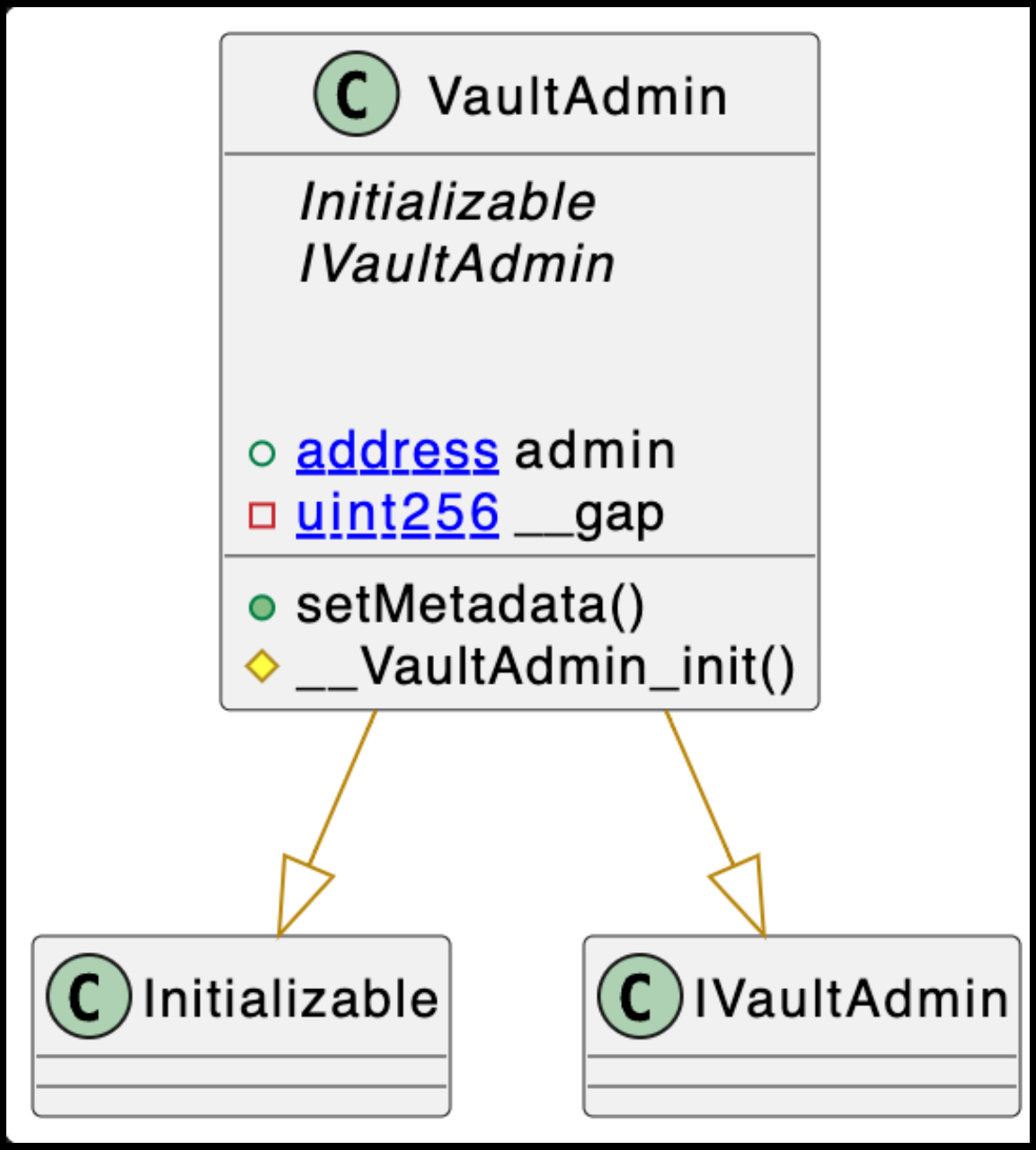



EthPrivateVault.sol

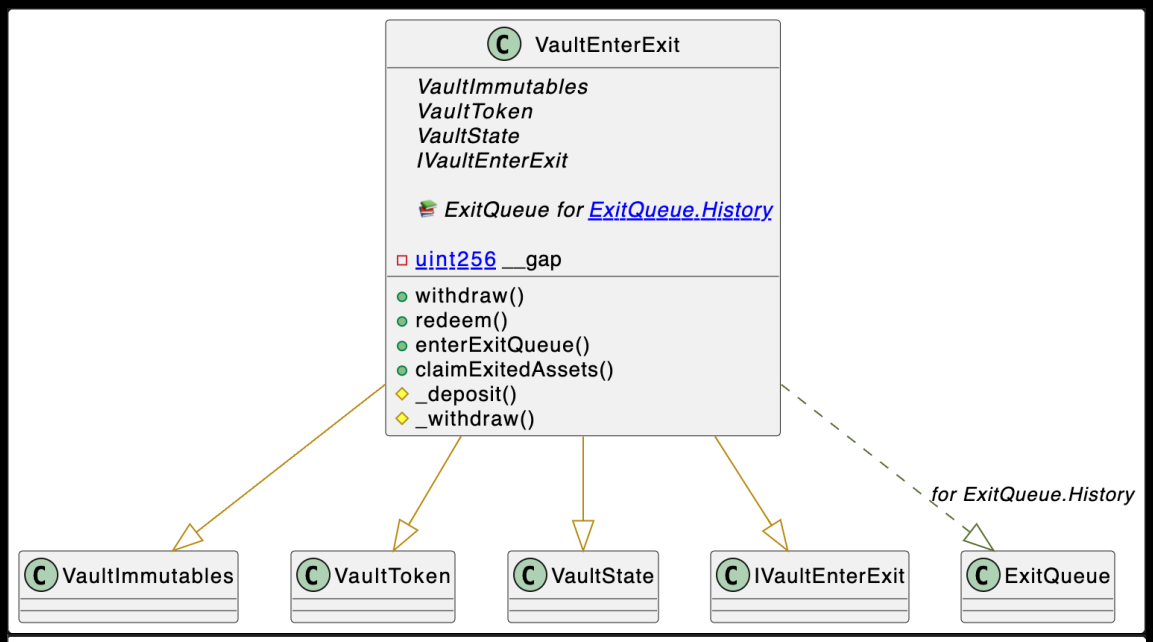


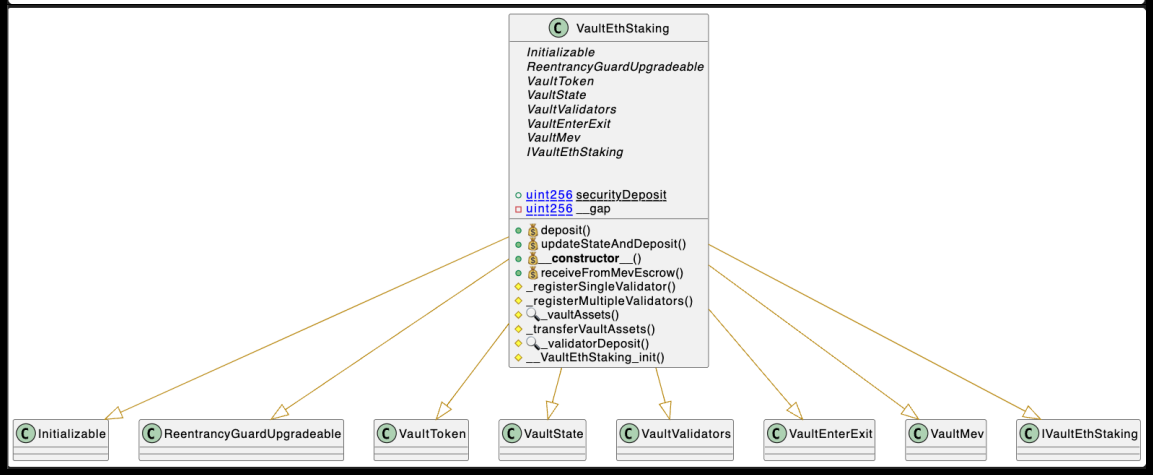
# CONTRACT UPGRADABILITY



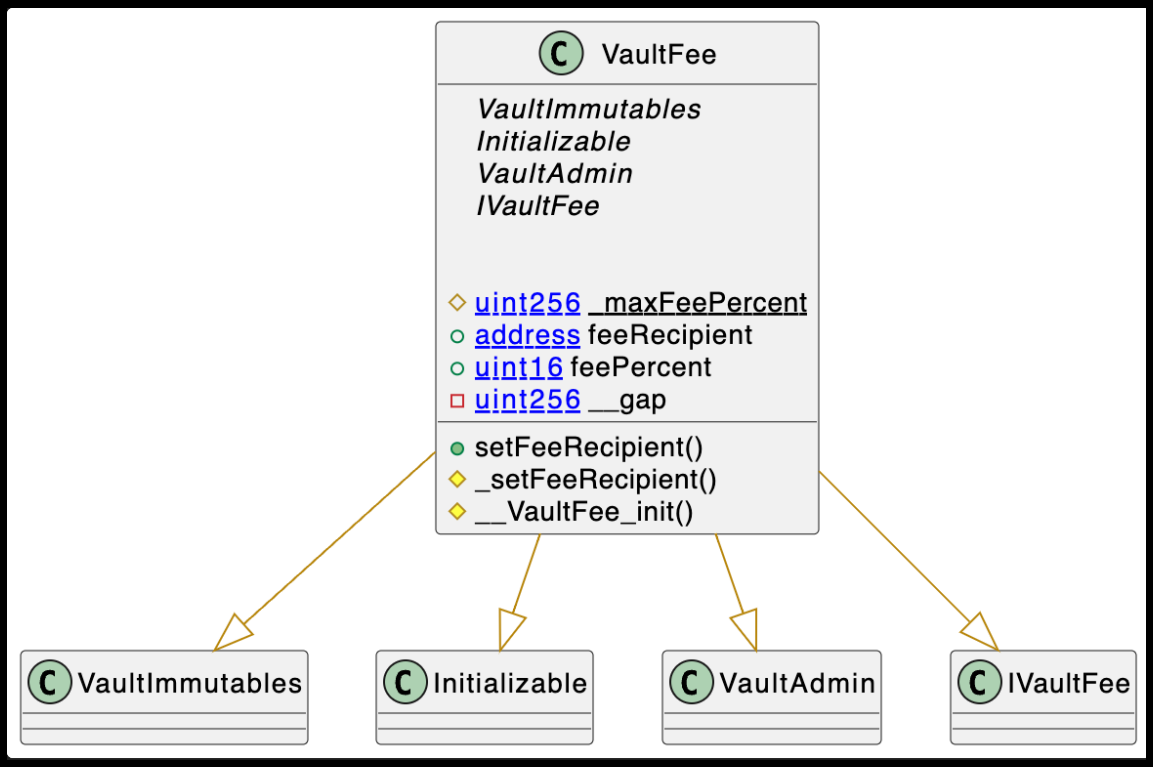

VaultAdmin
Initializable
IVaultAdmin
address admin
uint256 __gap
setMetadata()
__VaultAdmin_init()
Initializable
IVaultAdmin

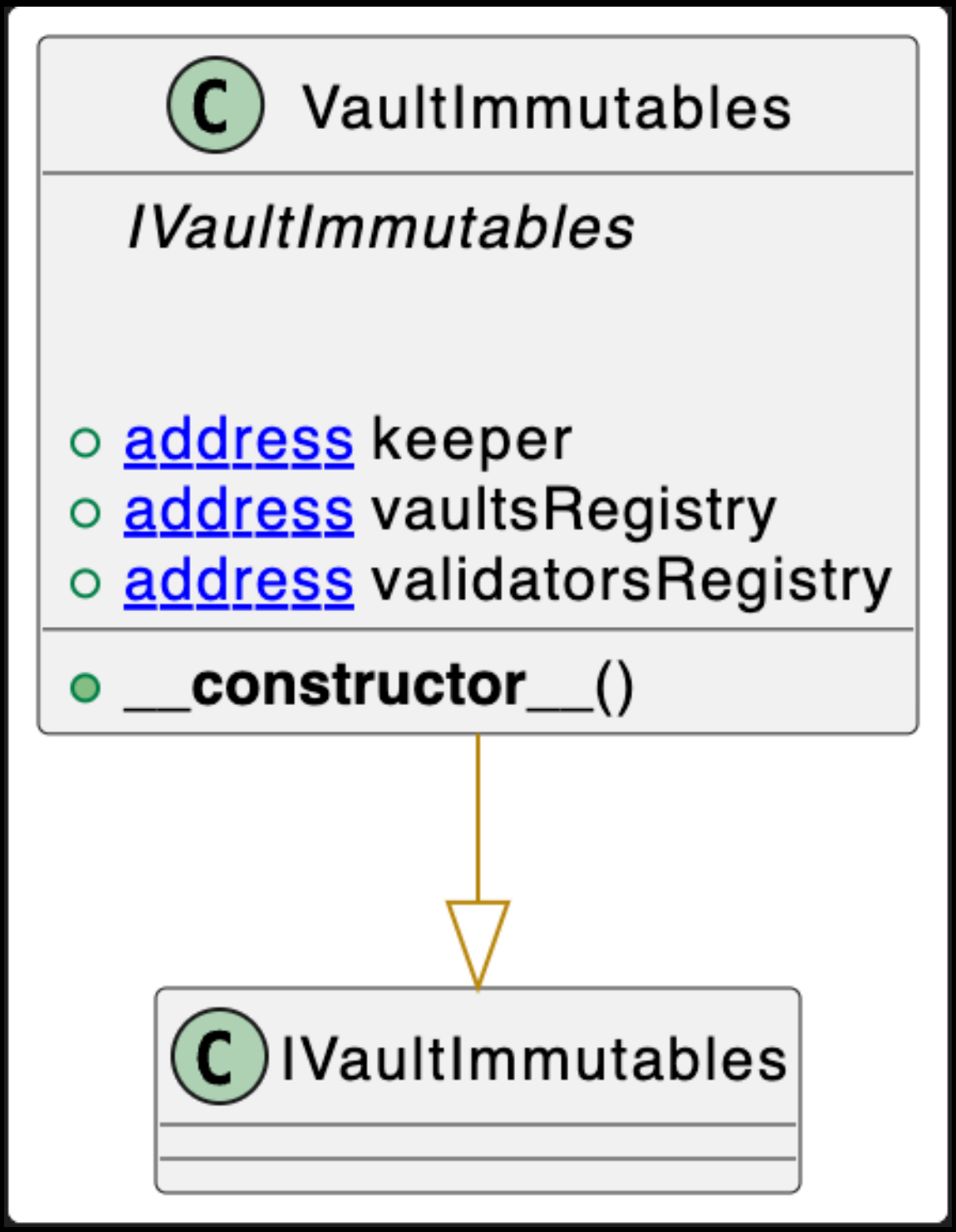
# CONTRACT UPGRADABILITY



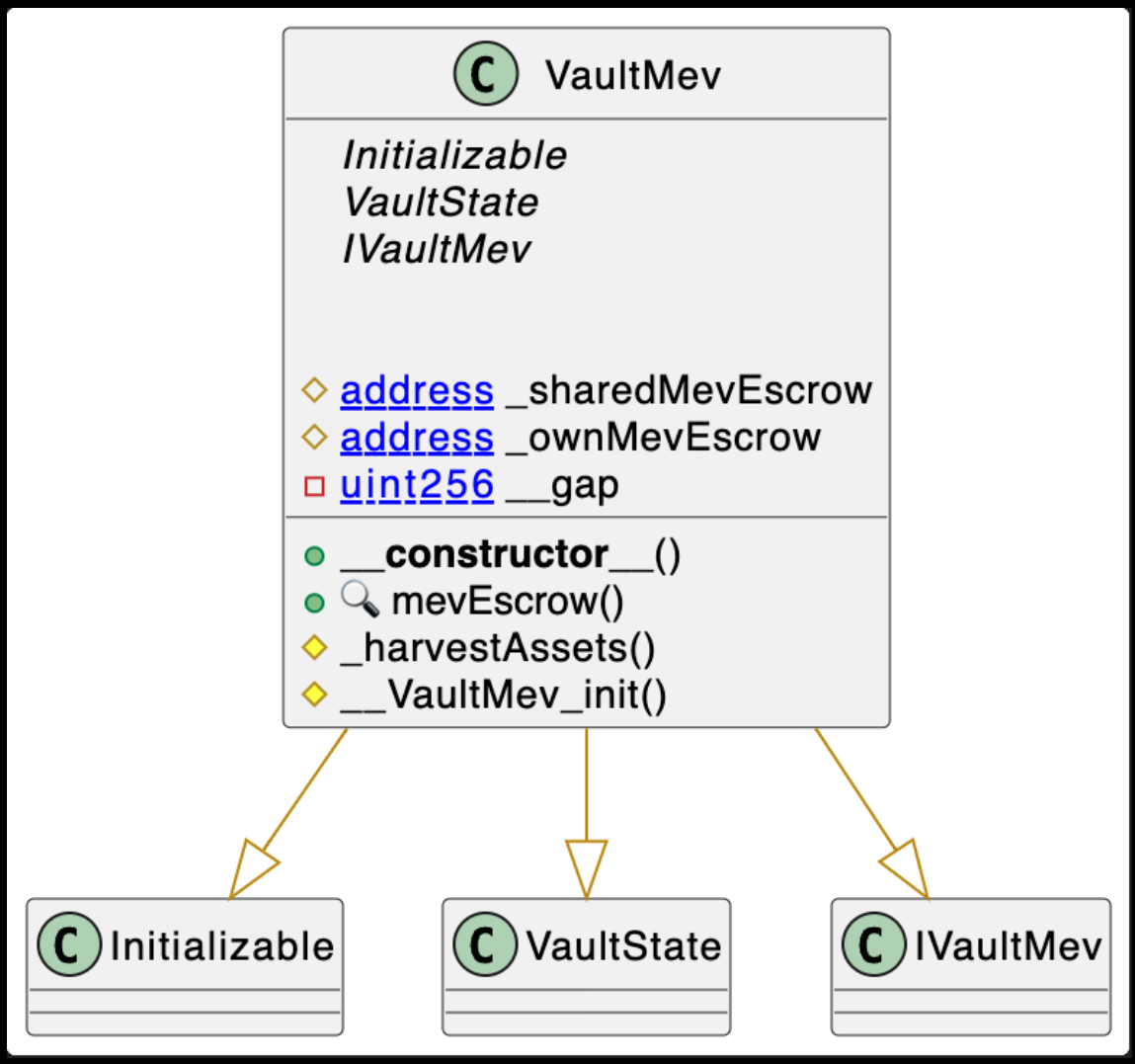



# CONTRACT UPGRADABILITY

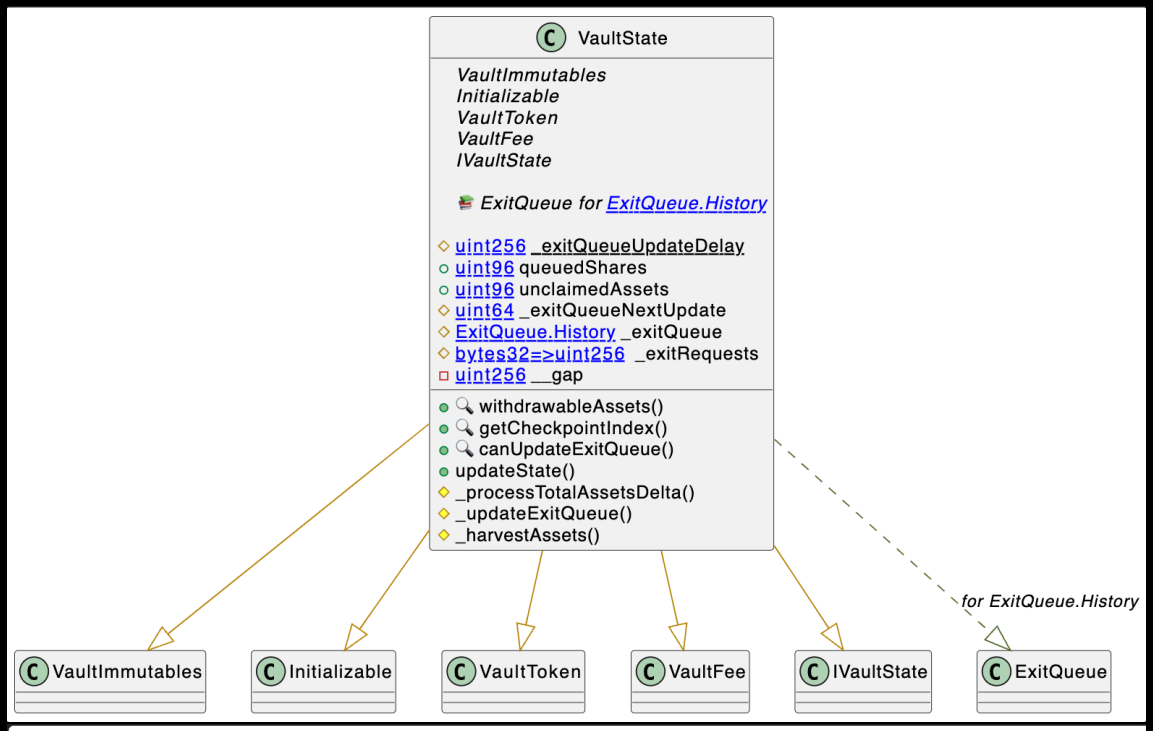


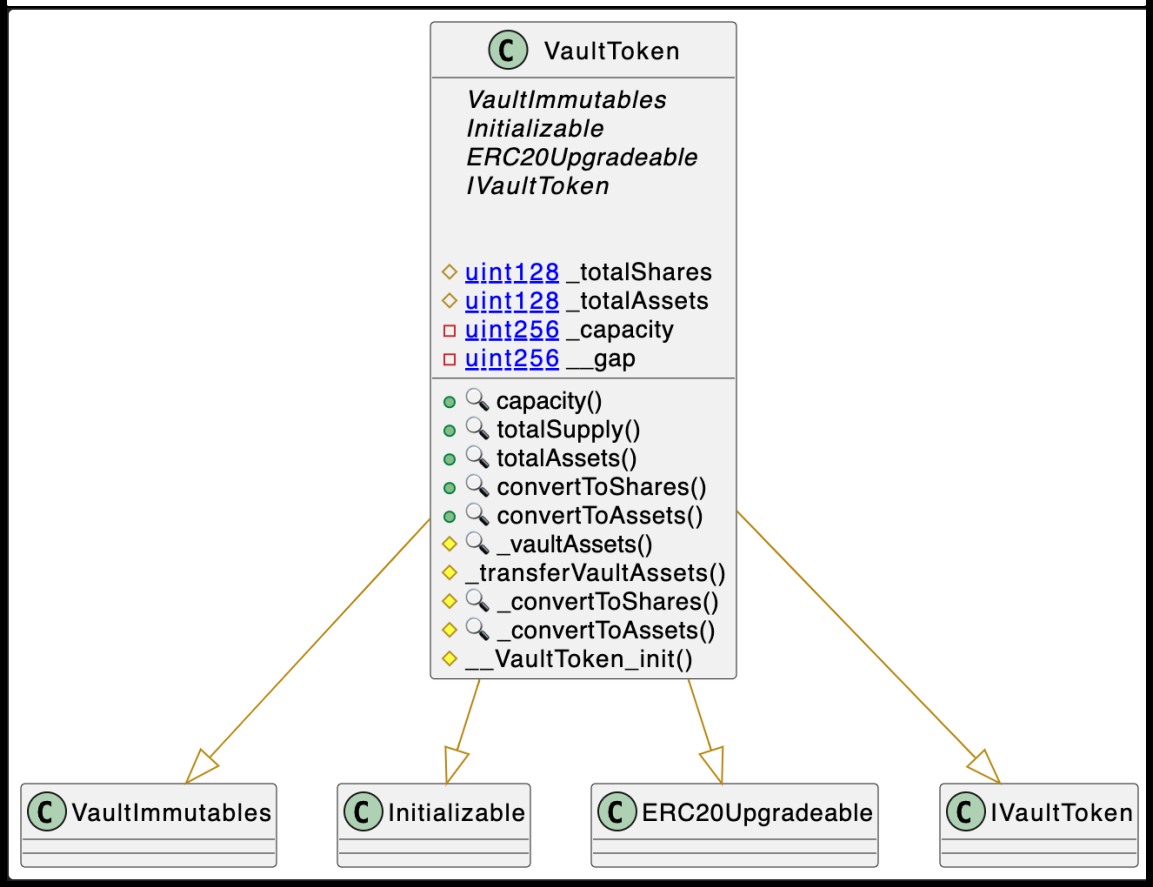

VaultImmutables
IVaultImmutables
address keeper
address vaultsRegistry
address validatorsRegistry
__constructor__()
IVaultImmutables

# CONTRACT UPGRADABILITY

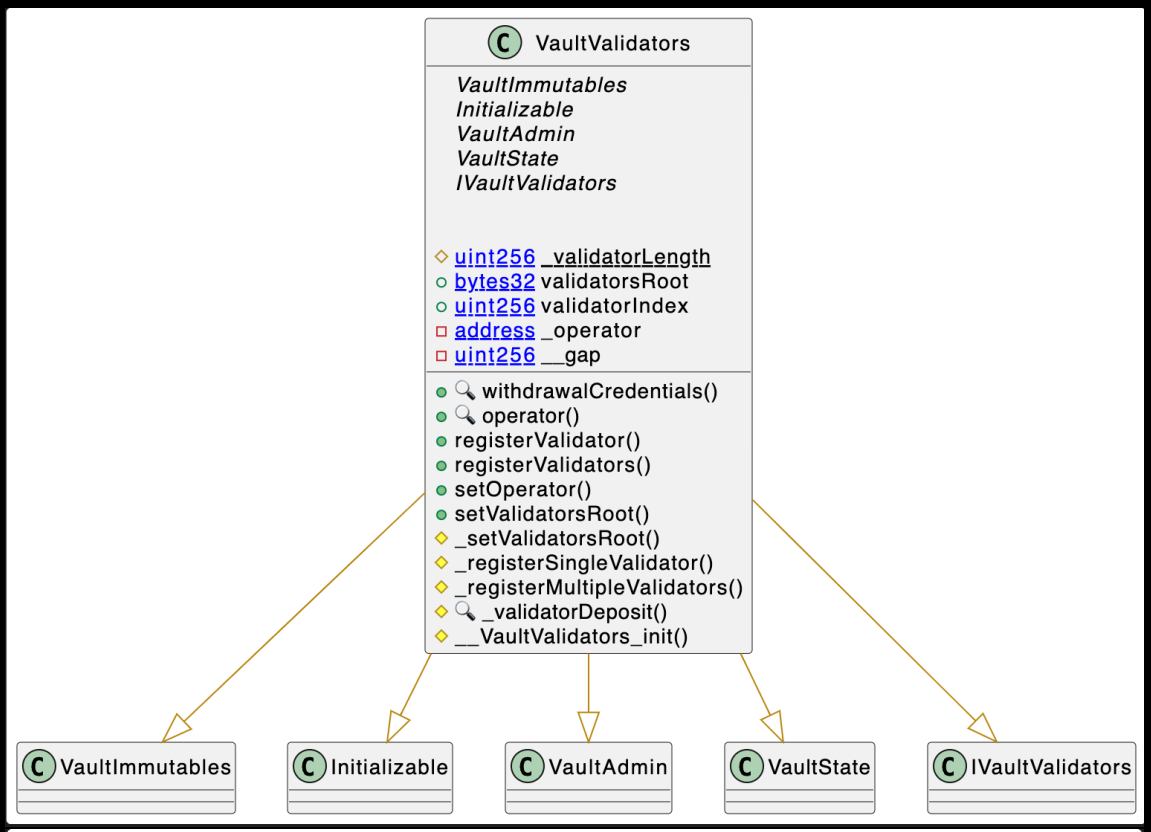


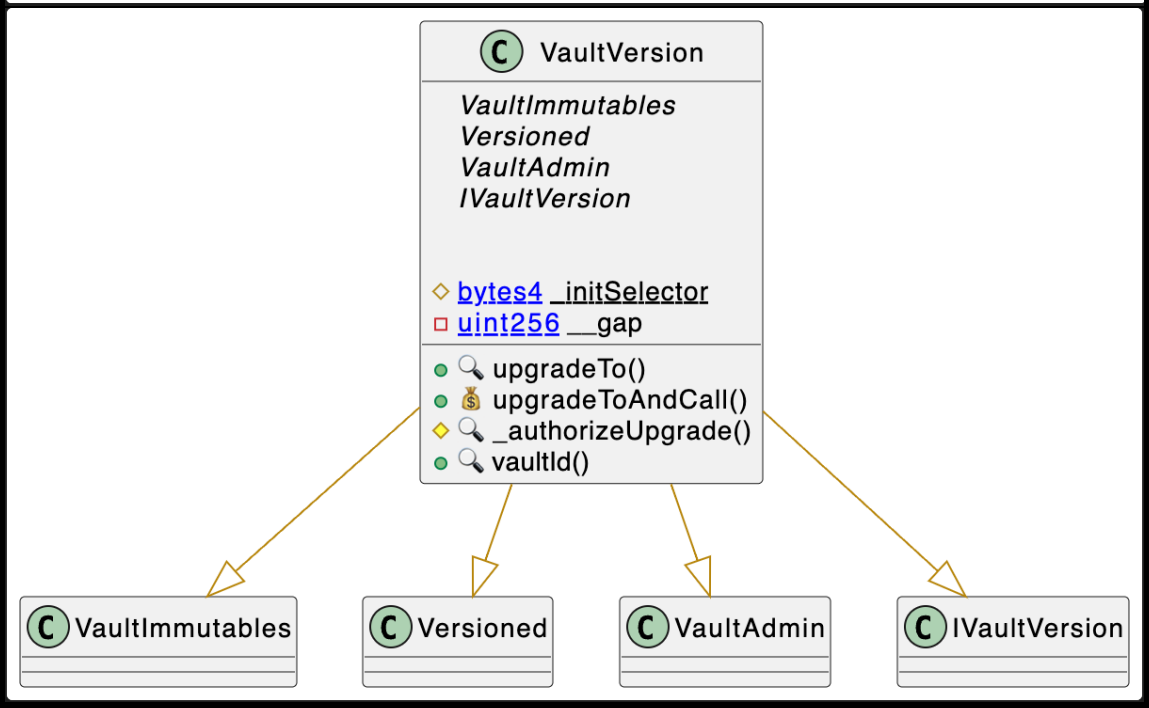
# CONTRACT UPGRADABILITY

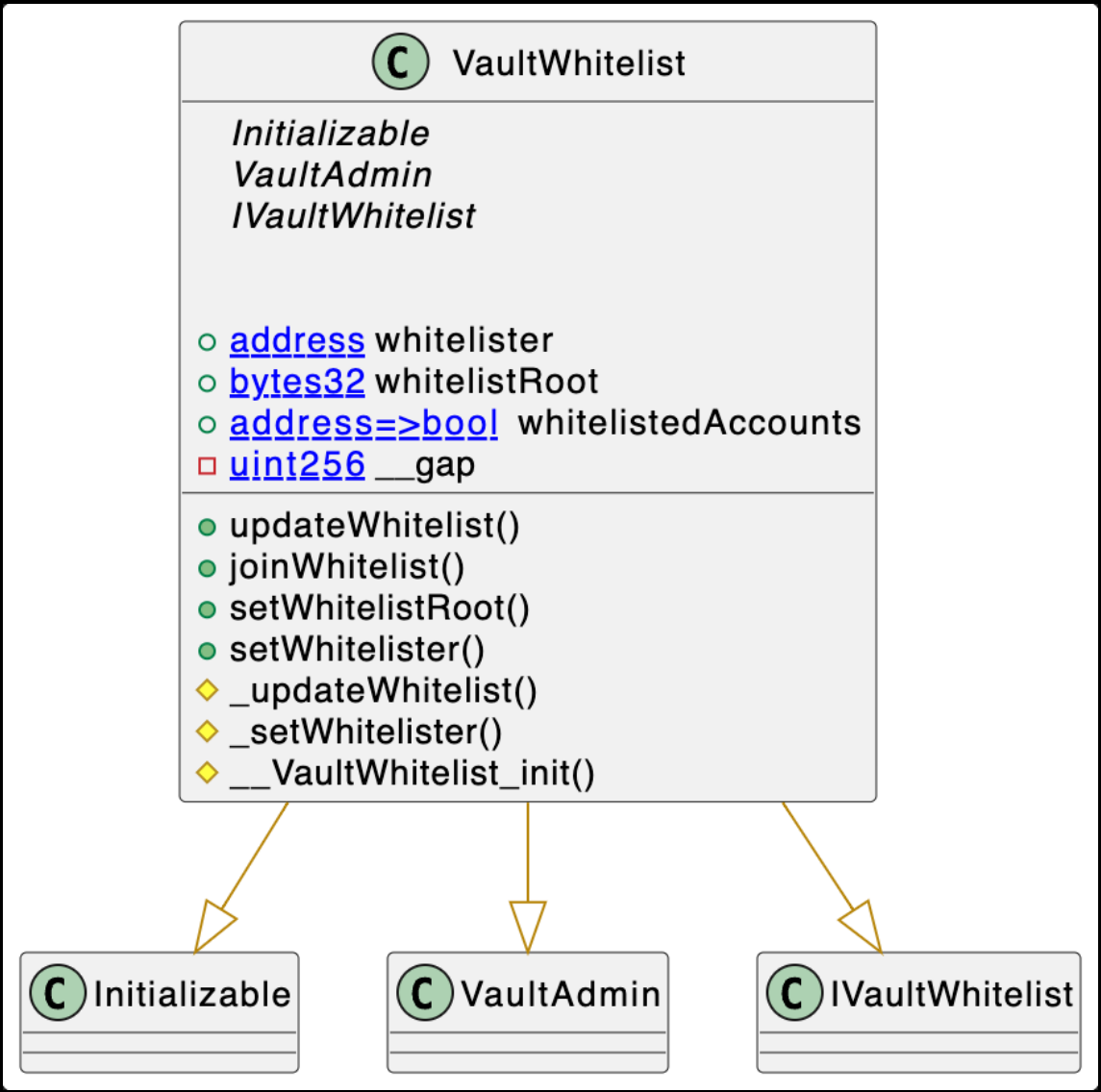


# CONTRACT UPGRADABILITY






## 6.2 Storage

No possibility of storage collision between the proxy and implementation was identified. The StakeWise team is using the standard UUPSUpgradeable along with ERC1967Upgrade.

The UUPSUpgradeable inherits from the ERC1967UpgradeUpgradeable which uses separate implementation, admin, and beacon storage slot.

The ERC1967Proxy inherits from the ERC1967Upgrade which uses separate

implementation, admin, and beacon storage slot.

## 6.3 Initialization

Every initialization function is correctly protected with the initializer modifier, preventing any possible re-initialization:

**Listing 6: Keeper.sol (Line 41)**

```
41   function initialize(address _owner, uint64 _rewardsDelay)
↳ external override initializer {
42     __KeeperRewards_init(_owner, _rewardsDelay);
43   }
```

**Listing 7: EthPrivateVault.sol (Line 40)**

```
38  function initialize(
39     bytes calldata params
40   ) external payable override(IEthVault, EthVault) initializer {
41     EthVaultInitParams memory initParams = abi.decode(params, (
↳ EthVaultInitParams));
42     __EthVault_init(initParams);
43     // whitelister is initially set to admin address
44     __VaultWhitelist_init(initParams.admin);
45   }
```

**Listing 8: EthVault.sol (Line 61)**

```
61   function initialize(bytes calldata params) external payable
↳ virtual override initializer {
62     __EthVault_init(abi.decode(params, (EthVaultInitParams)));
63   }
```

All the parent contracts are correctly initialized:

Keeper
- KeeperRewards [X]
- Ownable2StepUpgradeable [X]

- KeeperValidators [X] (no init function)

EthPrivateVault
- VaultWhitelist [X]
- EthVault [X]
- VaultToken [X]
- VaultAdmin [X]
- VaultFee [X]
- VaultValidators [X]
- VaultEthStaking [X]
- ReentrancyGuardUpgradeable [X]
- VaultMev [X]
- VaultVersion [X] (no init function)
- VaultEnterExit [X] (no init function)
- VaultState [X] (no init function)
- VaultImmutables [X] (no init function)

All relevant child contracts implement constructor with `_disableInitializers()`:

**Listing 9: Keeper.sol (Line 38)**

```
31   constructor(
32     IOracles _oracles,
33     IVaultsRegistry _vaultsRegistry,
34     IValidatorsRegistry _validatorsRegistry,
35     address sharedMevEscrow
36   ) KeeperValidators(_oracles, _vaultsRegistry,
↳ _validatorsRegistry, sharedMevEscrow) {
37     // disable initializers for the implementation contract
38     _disableInitializers();
39   }
```

**Listing 10: EthPrivateVault.sol (Line 35)**

```
30   constructor(
31     address _keeper,
32     address _vaultsRegistry,
33     address _validatorsRegistry,
34     address sharedMevEscrow
```

```
35   ) EthVault(_keeper, _vaultsRegistry, _validatorsRegistry,
↳ sharedMevEscrow) {}
```

**Listing 11: EthVault.sol (Line 57)**

```
51   constructor(
52     address _keeper,
53     address _vaultsRegistry,
54     address _validatorsRegistry,
55     address sharedMevEscrow
56   ) VaultImmutables(_keeper, _vaultsRegistry, _validatorsRegistry)
↳  VaultMev(sharedMevEscrow) {
57     _disableInitializers();
58   }
```

Also, the parent contract ERC20Upgradeable implements a constructor with _disableInitializers():

**Listing 12: EthVault.sol (Line 49)**

```
47   constructor() {
48     // disable initializers for the implementation contract
49     _disableInitializers();
50     _initialChainId = block.chainid;
51   }
```

## 6.4 Deployment

The eth-full-deploy.ts file contains an incomplete deployment script. However, fixtures.ts contains proof of concept of the deployment used within the integration tests.

The Keeper solution is deployed by means of the deployProxy functionality. The vaults are deployed via the EthVaultFactory contract. No instance of front-run possibility was identified.

# CONTRACT UPGRADABILITY

```ts
export const createKeeper = async function (
  owner: Wallet,
  oracles: Oracles,
  vaultsRegistry: VaultsRegistry,
  validatorsRegistry: Contract,
  sharedMevEscrow: SharedMevEscrow
): Promise<Keeper> {
  const factory = await ethers.getContractFactory('Keeper')
  const instance = await upgrades.deployProxy(factory, [owner.address, REWARDS_DELAY], {
    unsafeAllow: ['delegatecall'],
    constructorArgs: [
      oracles.address,
      vaultsRegistry.address,
      validatorsRegistry.address,
      sharedMevEscrow.address,
    ],
  })
  return (await instance.deployed()) as Keeper
}
```

```ts
export const createEthVaultFactory = async function (
  keeper: Keeper,
  vaultsRegistry: VaultsRegistry,
  sharedMevEscrow: SharedMevEscrow,
  validatorsRegistry: Contract
): Promise<EthVaultFactory> {
  const ethVault = await ethers.getContractFactory('EthVault')
  const ethVaultImpl = await upgrades.deployImplementation(ethVault, {
    unsafeAllow: ['delegatecall'],
    constructorArgs: [
      keeper.address,
      vaultsRegistry.address,
      validatorsRegistry.address,
      sharedMevEscrow.address,
    ],
  })

  const ethPrivateVault = await ethers.getContractFactory('EthPrivateVault')
  const ethPrivateVaultImpl = await upgrades.deployImplementation(ethPrivateVault, {
    unsafeAllow: ['delegatecall'],
    constructorArgs: [
      keeper.address,
      vaultsRegistry.address,
      validatorsRegistry.address,
      sharedMevEscrow.address,
    ],
  })

  const factory = await ethers.getContractFactory('EthVaultFactory')
  return (await factory.deploy(
    ethVaultImpl,
    ethPrivateVaultImpl,
    vaultsRegistry.address
  )) as EthVaultFactory
}
```

# AUTOMATED TESTING

# 7.1 STATIC ANALYSIS REPORT

## Description:

Halborn used automated testing techniques to enhance the coverage of certain areas of the smart contracts in scope. Among the tools used was Slither, a Solidity static analysis framework. After Halborn verified the smart contracts in the repository and was able to compile them correctly into their abis and binary format, Slither was run against the contracts. This tool can statically verify mathematical relationships between Solidity variables to detect invalid or inconsistent usage of the contracts' APIs across the entire code-base.

## Results:

### VaultsRegistry.sol

```
VaultsRegistry.constructor(address)._owner (vaults/VaultsRegistry.sol#28) shadows:
        - Ownable._owner (../node_modules/@openzeppelin/contracts/access/Ownable.sol#21) (state variable)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#local-variable-shadowing
```

### EthVaultFactory.sol

```
OwnMevEscrow.harvest() (vaults/ethereum/mev/OwnMevEscrow.sol#22-31) uses a dangerous strict equality:
        - assets == 0 (vaults/ethereum/mev/OwnMevEscrow.sol#26)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#dangerous-strict-equalities

EthVaultFactory.createVault(IEthVaultFactory.VaultParams,bool,bool).mevEscrow (vaults/ethereum/EthVaultFactory.sol#71) is a local variable n
ever initialized
ERC1967Upgrade._upgradeToAndCallUUPS(address,bytes,bool).slot (../node_modules/@openzeppelin/contracts/proxy/ERC1967/ERC1967Upgrade.sol#92)
is a local variable never initialized
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#uninitialized-local-variables
```

```
EthVaultFactory.constructor(address,address,IVaultsRegistry)._publicVaultImpl (vaults/ethereum/EthVaultFactory.sol#38) lacks a zero-check on
 :
                - publicVaultImpl = _publicVaultImpl (vaults/ethereum/EthVaultFactory.sol#39)
EthVaultFactory.constructor(address,address,IVaultsRegistry)._privateVaultImpl (vaults/ethereum/EthVaultFactory.sol#38) lacks a zero-check o
n :
                - privateVaultImpl = _privateVaultImpl (vaults/ethereum/EthVaultFactory.sol#40)
OwnMevEscrow.constructor(address)._vault (vaults/ethereum/mev/OwnMevEscrow.sol#17) lacks a zero-check on :
                - vault = address(_vault) (vaults/ethereum/mev/OwnMevEscrow.sol#18)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#missing-zero-address-validation
```

```
Reentrancy in EthVaultFactory.createVault(IEthVaultFactory.VaultParams,bool,bool) (vaults/ethereum/EthVaultFactory.sol#52-108):
        External calls:
        - vault = address(new ERC1967Proxy(privateVaultImpl,)) (vaults/ethereum/EthVaultFactory.sol#64)
        - vault = address(new ERC1967Proxy(publicVaultImpl,)) (vaults/ethereum/EthVaultFactory.sol#66)
        - IEthVault(vault).initialize{value: msg.value}(abi.encode(IEthVault.EthVaultInitParams(params.capacity,params.validatorsRoot,msg.se
nder,mevEscrow,params.feePercent,params.name,params.symbol,params.metadataIpfsHash))) (vaults/ethereum/EthVaultFactory.sol#77-90)
        - _vaultsRegistry.addVault(vault) (vaults/ethereum/EthVaultFactory.sol#93)
        External calls sending eth:
        - IEthVault(vault).initialize{value: msg.value}(abi.encode(IEthVault.EthVaultInitParams(params.capacity,params.validatorsRoot,msg.se
nder,mevEscrow,params.feePercent,params.name,params.symbol,params.metadataIpfsHash))) (vaults/ethereum/EthVaultFactory.sol#77-90)
        Event emitted after the call(s):
        - VaultCreated(msg.sender,vault,isPrivate,mevEscrow,params.capacity,params.feePercent,params.name,params.symbol) (vaults/ethereum/Et
hVaultFactory.sol#98-107)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities-3
```

```
EthVaultFactory.constructor(address,address,IVaultsRegistry) (vaults/ethereum/EthVaultFactory.sol#38-49) uses literals with too many digits:
        - _publicVaultCreateHash = keccak256(bytes)(abi.encodePacked(type()(ERC1967Proxy).creationCode,abi.encode(_publicVaultImpl,))) (vaul
ts/ethereum/EthVaultFactory.sol#43-45)
EthVaultFactory.constructor(address,address,IVaultsRegistry) (vaults/ethereum/EthVaultFactory.sol#38-49) uses literals with too many digits:
        - _privateVaultCreateHash = keccak256(bytes)(abi.encodePacked(type()(ERC1967Proxy).creationCode,abi.encode(_privateVaultImpl,))) (va
ults/ethereum/EthVaultFactory.sol#46-48)
EthVaultFactory.computeAddresses(address,bool) (vaults/ethereum/EthVaultFactory.sol#111-125) uses literals with too many digits:
        - ownMevEscrow = Create2.computeAddress(nonce,keccak256(bytes)(abi.encodePacked(type()(OwnMevEscrow).creationCode,abi.encode(vault))
)) (vaults/ethereum/EthVaultFactory.sol#121-124)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#too-many-digits
```

## EthPrivateVault.sol

```
ERC1967UpgradeUpgradeable._functionDelegateCall(address,bytes) (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/ERC1967UpgradeUpgradeable.sol#198-204) uses delegatecall to a input-controlled function id
        - (success,returndata) = target.delegatecall(data) (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/ERC1967UpgradeUpgradeable.sol#202)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#controlled-delegatecall

VaultValidators.registerValidators(IKeeperValidators.ApprovalParams,uint256[],bool[],bytes32[]) (vaults/modules/VaultValidators.sol#93-136) performs a multiplication on the result of a division:
        - validatorsCount = keeperParams.validators.length / _validatorLength (vaults/modules/VaultValidators.sol#103)
        - withdrawableAssets() < _validatorDeposit() * validatorsCount (vaults/modules/VaultValidators.sol#104)
VaultValidators.registerValidators(IKeeperValidators.ApprovalParams,uint256[],bool[],bytes32[]) (vaults/modules/VaultValidators.sol#93-136) performs a multiplication on the result of a division:
        - validatorsCount = keeperParams.validators.length / _validatorLength (vaults/modules/VaultValidators.sol#103)
        - validatorsCount == 0 || validatorsCount * _validatorLength != keeperParams.validators.length || indexes.length != validatorsCount (vaults/modules/VaultValidators.sol#111-113)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#divide-before-multiply

VaultToken._convertToAssets(uint256,uint256,uint256,Math.Rounding) (vaults/modules/VaultToken.sol#90-97) uses a dangerous strict equality:
        - (totalShares == 0) (vaults/modules/VaultToken.sol#96)
VaultToken._convertToShares(uint256,uint256,uint256,Math.Rounding) (vaults/modules/VaultToken.sol#73-85) uses a dangerous strict equality:
        - (assets == 0 || totalShares == 0) (vaults/modules/VaultToken.sol#81-84)
VaultState._processTotalAssetsDelta(int256) (vaults/modules/VaultState.sol#74-125) uses a dangerous strict equality:
        - feeRecipientShares == 0 (vaults/modules/VaultState.sol#111)
VaultState._updateExitQueue() (vaults/modules/VaultState.sol#130-165) uses a dangerous strict equality:
        - _queuedShares == 0 (vaults/modules/VaultState.sol#133)
VaultState._updateExitQueue() (vaults/modules/VaultState.sol#130-165) uses a dangerous strict equality:
        - exitedAssets == 0 (vaults/modules/VaultState.sol#141)
VaultState._updateExitQueue() (vaults/modules/VaultState.sol#130-165) uses a dangerous strict equality:
        - burnedShares == 0 (vaults/modules/VaultState.sol#145)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#dangerous-strict-equalities

Reentrancy in VaultEthStaking.updateStateAndDeposit(address,address,IKeeperRewards.HarvestParams) (vaults/modules/VaultEthStaking.sol#47-54):
        External calls:
        - updateState(harvestParams) (vaults/modules/VaultEthStaking.sol#52)
                - (totalAssetsDelta,unlockedMevDelta) = IKeeperRewards(keeper).harvest(harvestParams) (vaults/modules/VaultMev.sol#44-46)
                - ISharedMevEscrow(_mevEscrow).harvest(unlockedMevDelta) (vaults/modules/VaultMev.sol#53)
                - totalAssetsDelta + int256(IOwnMevEscrow(_mevEscrow).harvest()) (vaults/modules/VaultMev.sol#59)
        State variables written after the call(s):
        - deposit(receiver,referrer) (vaults/modules/VaultEthStaking.sol#53)
                - _totalAssets = SafeCast.toUint128(totalAssetsAfter) (vaults/modules/VaultEnterExit.sol#147)
        VaultToken._totalAssets (vaults/modules/VaultToken.sol#21) can be used in cross function reentrancies:
        - VaultEnterExit._deposit(address,uint256,address) (vaults/modules/VaultEnterExit.sol#127-157)
        - VaultState._processTotalAssetsDelta(int256) (vaults/modules/VaultState.sol#74-125)
        - VaultState._updateExitQueue() (vaults/modules/VaultState.sol#130-165)
        - VaultEnterExit._withdraw(address,address,uint256,uint256) (vaults/modules/VaultEnterExit.sol#166-191)
        - VaultToken.convertToAssets(uint256) (vaults/modules/VaultToken.sol#50-52)
        - VaultToken.convertToShares(uint256) (vaults/modules/VaultToken.sol#45-47)
        - VaultToken.totalAssets() (vaults/modules/VaultToken.sol#40-42)
        - VaultEnterExit.withdraw(uint256,address,address) (vaults/modules/VaultEnterExit.sol#23-31)
        - deposit(receiver,referrer) (vaults/modules/VaultEthStaking.sol#53)
                - _totalShares += SafeCast.toUint128(shares) (vaults/modules/VaultEnterExit.sol#146)
        VaultToken._totalShares (vaults/modules/VaultToken.sol#20) can be used in cross function reentrancies:
        - VaultEnterExit._deposit(address,uint256,address) (vaults/modules/VaultEnterExit.sol#127-157)
        - VaultState._processTotalAssetsDelta(int256) (vaults/modules/VaultState.sol#74-125)
        - VaultState._updateExitQueue() (vaults/modules/VaultState.sol#130-165)
        - VaultEnterExit._withdraw(address,address,uint256,uint256) (vaults/modules/VaultEnterExit.sol#166-191)
        - VaultToken.convertToAssets(uint256) (vaults/modules/VaultToken.sol#50-52)
        - VaultToken.convertToShares(uint256) (vaults/modules/VaultToken.sol#45-47)
        - VaultToken.totalSupply() (vaults/modules/VaultToken.sol#35-37)
        - VaultEnterExit.withdraw(uint256,address,address) (vaults/modules/VaultEnterExit.sol#23-31)
        - deposit(receiver,referrer) (vaults/modules/VaultEthStaking.sol#53)
                - balanceOf[to] += shares (vaults/modules/VaultEnterExit.sol#152)
        ERC20Upgradeable.balanceOf (base/ERC20Upgradeable.sol#28) can be used in cross function reentrancies:
        - VaultEnterExit._deposit(address,uint256,address) (vaults/modules/VaultEnterExit.sol#127-157)
        - VaultState._processTotalAssetsDelta(int256) (vaults/modules/VaultState.sol#74-125)
        - ERC20Upgradeable._transfer(address,address,uint256) (base/ERC20Upgradeable.sol#142-153)
        - VaultEnterExit._withdraw(address,address,uint256,uint256) (vaults/modules/VaultEnterExit.sol#166-191)
        - ERC20Upgradeable.balanceOf (base/ERC20Upgradeable.sol#28)
        - VaultEnterExit.enterExitQueue(uint256,address,address) (vaults/modules/VaultEnterExit.sol#45-73)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities-1

Multicall.multicall(bytes[]) (base/Multicall.sol#15-31) has external calls inside a loop: (success,result) = address(this).delegatecall(data[i]) (base/Multicall.sol#18)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation/#calls-inside-a-loop

Reentrancy in VaultValidators.registerValidator(IKeeperValidators.ApprovalParams,bytes32[]) (vaults/modules/VaultValidators.sol#55-90):
        External calls:
        - IKeeperValidators(keeper).approveValidators(keeperParams) (vaults/modules/VaultValidators.sol#60)
        State variables written after the call(s):
        - validatorIndex = currentIndex + 1 (vaults/modules/VaultValidators.sol#88)
Reentrancy in VaultValidators.registerValidators(IKeeperValidators.ApprovalParams,uint256[],bool[],bytes32[]) (vaults/modules/VaultValidators.sol#93-136):
        External calls:
        - IKeeperValidators(keeper).approveValidators(keeperParams) (vaults/modules/VaultValidators.sol#100)
        State variables written after the call(s):
        - validatorIndex += validatorsCount (vaults/modules/VaultValidators.sol#134)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities-2
```

```
Reentrancy in VaultEthStaking._registerMultipleValidators(bytes,uint256[]) (vaults/modules/VaultEthStaking.sol#82-121):
        External calls:
        - IEthValidatorsRegistry(validatorsRegistry).deposit{value: validatorDeposit}(publicKey,withdrawalCreds,validator,bytes32(validator)
) (vaults/modules/VaultEthStaking.sol#107-112)
        Event emitted after the call(s):
        - ValidatorRegistered(publicKey) (vaults/modules/VaultEthStaking.sol#119)
Reentrancy in VaultEthStaking._registerSingleValidator(bytes) (vaults/modules/VaultEthStaking.sol#69-79):
        External calls:
        - IEthValidatorsRegistry(validatorsRegistry).deposit{value: _validatorDeposit()}(publicKey,withdrawalCredentials(),validator,bytes32
(validator)) (vaults/modules/VaultEthStaking.sol#71-76)
        Event emitted after the call(s):
        - ValidatorRegistered(publicKey) (vaults/modules/VaultEthStaking.sol#78)
Reentrancy in VaultEthStaking.updateStateAndDeposit(address,address,IKeeperRewards.HarvestParams) (vaults/modules/VaultEthStaking.sol#47-54)
:
        External calls:
        - updateState(harvestParams) (vaults/modules/VaultEthStaking.sol#52)
                - (totalAssetsDelta,unlockedMevDelta) = IKeeperRewards(keeper).harvest(harvestParams) (vaults/modules/VaultMev.sol#44-46)
                - ISharedMevEscrow(_mevEscrow).harvest(unlockedMevDelta) (vaults/modules/VaultMev.sol#53)
                - totalAssetsDelta + int256(IOwnMevEscrow(_mevEscrow).harvest()) (vaults/modules/VaultMev.sol#59)
        Event emitted after the call(s):
        - Deposit(msg.sender,to,assets,shares,referrer) (vaults/modules/VaultEnterExit.sol#156)
                - deposit(receiver,referrer) (vaults/modules/VaultEthStaking.sol#53)
        - Transfer(address(0),to,shares) (vaults/modules/VaultEnterExit.sol#155)
                - deposit(receiver,referrer) (vaults/modules/VaultEthStaking.sol#53)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#reentrancy-vulnerabilities-3
```

```
Variable VaultToken._totalAssets (vaults/modules/VaultToken.sol#21) is too similar to VaultToken._convertToShares(uint256,uint256,uint256,Ma
th.Rounding).totalAssets_ (vaults/modules/VaultToken.sol#76)
Variable VaultToken._totalAssets (vaults/modules/VaultToken.sol#21) is too similar to VaultToken._convertToAssets(uint256,uint256,uint256,Ma
th.Rounding).totalAssets_ (vaults/modules/VaultToken.sol#93)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#variable-names-too-similar
```

## Keeper.sol

```
ERC1967UpgradeUpgradeable._functionDelegateCall(address,bytes) (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/ERC1967Upg
radeUpgradeable.sol#198-204) uses delegatecall to a input-controlled function id
        - (success,returndata) = target.delegatecall(data) (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/ERC1967Upgrade
Upgradeable.sol#202)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#controlled-delegatecall

ERC1967UpgradeUpgradeable._upgradeToAndCallUUPS(address,bytes,bool).slot (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/
ERC1967UpgradeUpgradeable.sol#98) is a local variable never initialized
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#uninitialized-local-variables

ERC1967UpgradeUpgradeable._upgradeToAndCallUUPS(address,bytes,bool) (../node_modules/@openzeppelin/contracts-upgradeable/proxy/ERC1967/ERC19
67UpgradeUpgradeable.sol#87-105) ignores return value by IERC1822ProxiableUpgradeable(newImplementation).proxiableUUID() (../node_modules/@o
penzeppelin/contracts-upgradeable/proxy/ERC1967/ERC1967UpgradeUpgradeable.sol#98-102)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#unused-return
```

```
Keeper.initialize(address,uint64)._owner (keeper/Keeper.sol#42) shadows:
        - OwnableUpgradeable._owner (../node_modules/@openzeppelin/contracts-upgradeable/access/OwnableUpgradeable.sol#22) (state variable)
KeeperRewards.__KeeperRewards_init(address,uint64)._owner (keeper/KeeperRewards.sol#238) shadows:
        - OwnableUpgradeable._owner (../node_modules/@openzeppelin/contracts-upgradeable/access/OwnableUpgradeable.sol#22) (state variable)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#local-variable-shadowing
```

```
KeeperRewards.canUpdateRewards() (keeper/KeeperRewards.sol#117-124) uses timestamp for comparisons
        Dangerous comparisons:
        - _lastRewardsTimestamp + rewardsDelay < block.timestamp (keeper/KeeperRewards.sol#122)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#block-timestamp
```

```
Function IValidatorsRegistry.get_deposit_root() (interfaces/IValidatorsRegistry.sol#22) is not in mixedCase
Parameter Keeper.initialize(address,uint64)._owner (keeper/Keeper.sol#42) is not in mixedCase
Parameter Keeper.initialize(address,uint64)._rewardsDelay (keeper/Keeper.sol#42) is not in mixedCase
Parameter KeeperRewards.setRewardsDelay(uint64)._rewardsDelay (keeper/KeeperRewards.sol#207) is not in mixedCase
Function KeeperRewards.__KeeperRewards_init(address,uint64) (keeper/KeeperRewards.sol#238-245) is not in mixedCase
Parameter KeeperRewards.__KeeperRewards_init(address,uint64)._owner (keeper/KeeperRewards.sol#238) is not in mixedCase
Parameter KeeperRewards.__KeeperRewards_init(address,uint64)._rewardsDelay (keeper/KeeperRewards.sol#238) is not in mixedCase
Constant KeeperRewards._rewardsRootTypeHash (keeper/KeeperRewards.sol#20-23) is not in UPPER_CASE_WITH_UNDERSCORES
Variable KeeperRewards.__gap (keeper/KeeperRewards.sol#252) is not in mixedCase
Constant KeeperValidators._registerValidatorsTypeHash (keeper/KeeperValidators.sol#18-21) is not in UPPER_CASE_WITH_UNDERSCORES
Constant KeeperValidators._updateExitSigTypeHash (keeper/KeeperValidators.sol#23-24) is not in UPPER_CASE_WITH_UNDERSCORES
Variable KeeperValidators.__gap (keeper/KeeperValidators.sol#115) is not in mixedCase
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#conformance-to-solidity-naming-conventions
```

## OwnMevEscrow.sol

```
OwnMevEscrow.harvest() (vaults/ethereum/mev/OwnMevEscrow.sol#22-31) uses a dangerous strict equality:
        - assets == 0 (vaults/ethereum/mev/OwnMevEscrow.sol#26)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#dangerous-strict-equalities

OwnMevEscrow.constructor(address)._vault (vaults/ethereum/mev/OwnMevEscrow.sol#17) lacks a zero-check on :
                - vault = address(_vault) (vaults/ethereum/mev/OwnMevEscrow.sol#18)
Reference: https://github.com/crytic/slither/wiki/Detector-Documentation#missing-zero-address-validation
```

- Re-entrancy issues are false positives.
- Usage of timestamp for comparisons is false positive.

- Vast number of findings are false positives.
- Findings related to third-party libraries (OpenZeppelin) were omitted.
- Findings related to the different versions of Solidity usage and Pragma versions were omitted.
- The scan of SharedMevEscrow.sol and Oracles.sol yielded no result.
- The scan of EthVault.sol is included in the scan of EthPrivateVault.sol
- No major issues were found by Slither.

# 7.2 AUTOMATED SECURITY SCAN

## Description:

Halborn used automated security scanners to assist with detection of well-known security issues and to identify low-hanging fruits on the targets for this engagement. Among the tools used was MythX, a security analysis service for Ethereum smart contracts. MythX performed a scan on the smart contracts and sent the compiled results to the analyzers in order to locate any vulnerabilities.

## Results:

### EthPrivateVault.sol

Report for contracts/base/Multicall.sol
https://dashboard.mythx.io/#/console/analyses/2f176cda-7efd-4b47-bff4-d9e815edce46

| Line | SWC Title | Severity | Short Description |
|---|---|---|---|
| 15 | (SWC-118) Incorrect Constructor Name | Medium | Potential incorrect constructor name "multicall". |

### Oracles.sol

Report for contracts/keeper/Oracles.sol
https://dashboard.mythx.io/#/console/analyses/1d10abee-4a80-4acd-9f9b-26392c0753ce

| Line | SWC Title | Severity | Short Description |
|---|---|---|---|
| 41 | (SWC-110) Assert Violation | Unknown | Out of bounds array access |
| 43 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "++" discovered |
| 58 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "+=" discovered |
| 71 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "-" discovered |
| 71 | (SWC-101) Integer Overflow and Underflow | Unknown | Compiler-rewritable "<uint> - 1" discovered |
| 117 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "*" discovered |
| 127 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "+" discovered |
| 137 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "++" discovered |
| 138 | (SWC-101) Integer Overflow and Underflow | Unknown | Arithmetic operation "+=" discovered |

- The scan of EthVault.sol is included in the scan of EthPrivateVault.sol
- The scan of VaultsRegistry.sol, EthVaultFactory.sol.sol, OwnMevEscrow.sol, SharedMevEscrow.sol, and Keeper.sol yielded no result.

- No major issues were found by Mythx.

THANK YOU FOR CHOOSING

// HALBORN