Oracle Linux 10

Working With UEFI Secure Boot

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Contents

Preface

Preface

Oracle Linux 10: Working With UEFI Secure Boot provides background and other related information about the UEFI Secure Boot feature and its implementation in Oracle Linux.

> **Note:**
>
> UEFI Secure Boot is also more commonly referred to as "Secure Boot" in this document.

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1 About UEFI Secure Boot

For an OS to be secure, every layer below the OS layer must also be secure. Running software on a CPU is unsafe if the software can not be trusted to run code correctly. Likewise, if the boot loader is tampered with or the firmware itself is compromised, the kernel that's booted can not be trusted.

UEFI Secure Boot is a platform feature within the UEFI specification that ensures that the system boots by using only the software that's trusted by the hardware manufacturer. Secure Boot provides a verification mechanism where the firmware validates a boot loader before running the loader. This mechanism checks that the code that's run by a system's firmware is trusted. When the system starts, the firmware checks the signature for each piece of boot software, including the firmware drivers and the OS itself. If the signatures are valid, the system boots, and the firmware relinquishes control to the OS.

Secure Boot uses cryptographic checksums and signatures to prevent malicious code from being loaded and run early in the boot process before the OS has loaded. Every program that's loaded by the firmware includes a signature and a checksum and undergoes the same validation by the firmware. Secure Boot stops all untrusted programs from running to prevent any unexpected or unauthorized code from operating in the UEFI-based environment.

Most UEFI compliant systems ship with Secure Boot enabled. These systems are also loaded with Microsoft keys. Thus, binaries that are signed by Microsoft are also trusted by the firmware. By default, these systems don't run any unsigned code. However, you can change the firmware configuration to either enroll more signing keys or to disable Secure Boot.

Secure Boot doesn't prevent users from controlling their own systems. Users can enroll extra keys into the system to enable the signing of other programs. Further, on some systems with Secure Boot enabled by default, users can also remove platform provided keys to force firmware to trust user signed binaries only.

How the Secure Boot Process Works

Each step in the Secure Boot process checks a cryptographic signature on the executable of the next step. The BIOS checks a signature on the boot loader and then the boot loader checks the signatures on all the kernel objects that the boot loader loads.

Objects in the chain are typically signed by the software manufacturer by using private keys that match the public keys already in the BIOS. Altered modules or objects in the boot chain would have mismatching signatures, which prevents the device from booting the image. Otherwise, the platform boots successfully.

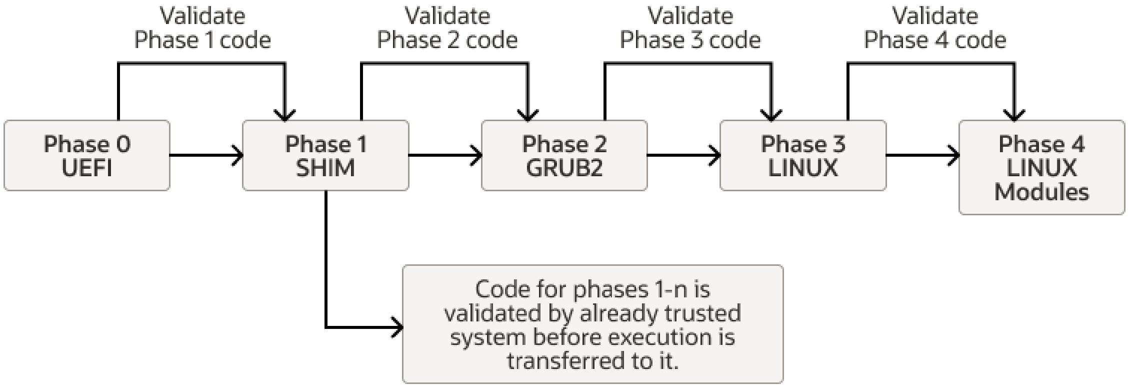
The following are required to meet the goals of Secure Boot:

- The Linux boot loader must provide authentication of the Linux kernel.
- The Linux distribution must provide further security enforcement in the kernels that it distributes.

The Shim first stage boot loader program provides a way to meet both of these goals. For more explanation, see Description of the Shim First Stage Boot Loader.

The following figure illustrates the Secure Boot process:

Figure 1-1 Secure Boot Process



Phase 0: The UEFI checks whether Secure Boot is enabled and loads the keys that it stores for this purpose from the UEFI Secure Boot key database.

Phase 1: The Shim software loads. UEFI first validates the signature that was used to sign the Shim. If the signature is valid, the Shim loading can continue. Otherwise, the Shim is unable to load. Thereafter, the loaded Shim is responsible for validating all code. The Shim maintains its own MOK database, where other keys are stored for validation purposes.

Phase 2: The Shim software validates the key that's used to sign the GRUB2 secondary bootloader. If validation passes, GRUB2 loads. the Shim can then validate the keys that are used to sign the kernel images available to GRUB2.

Phase 3: A valid kernel loads. The kernel has read access to the keys in the UEFI Secure Boot key database and the MOK database. The kernel also has its own set of trusted keys that are built into the kernel image itself.

Phase 4: The kernel validates the keys that are used to sign all other modules that need to be loaded, including signed kernel images on `kexec` operations. Depending on the kernel implementation, the kernel would trust the keys in the UEFI Secure Boot database or the MOK database. Or, it would only trust the keys that are built into the kernel image itself. Note that for `kexec` signed kernel images signature validation, the following keys can be used: UEFI, DB/MOK, DB keys, and kernel builtin keys.

Secure Boot Limitations

Secure Boot can impose limitations on the system and its operations. The feature is purposely designed to restrict the applications that can run before the OS is booted because after the system is booted, the OS has no way of identifying any programs that were booted earlier or even whether the system was booted securely. For example, if a boot kit is injected into the system before the system boot, Secure Boot could be rendered useless. Or, if an attacker disables Secure Boot and installs malware that could be interpreted by the OS as platform security, the system is compromised..

Secure Boot can also have an impact on the use of some features and user actions, including the activation of the Kernel Lockdown feature. This feature prevents both direct and indirect access to a running kernel image to protect the kernel image from unauthorized modifications and prevent access to the security and cryptographic data in the kernel's memory.

When Lockdown mode is activated, some features that you typically use to revise the kernel might be affected, including the following:

- Loading of kernel modules that aren't signed by a trusted key.
- Use of `kexec` tools to start an unsigned kernel image.
- Hibernation and resume from hibernation modes.
- User space access to physical memory and I/O ports.
- Module parameters that enable you to set memory and I/O port addresses.
- On x86_64 systems only, writing to MSRs through `/dev/cpu/*/msr`. On Arm platforms, `/dev/cpu/*` isn't implemented.
- Use of custom ACPI methods and tables.
- Advanced Configuration and Power Interface (ACPI) and ACPI Platform Error Interface (APEI) error injection.

If you need to use any of these features, you can disable Secure Boot through the system's Extensible Firmware Interface (EFI) setup program. For further information, see Enabling and Disabling Secure Boot.

About Secure Boot Keys

All Secure Boot key types are examples of the Public Key Infrastructure (PKI). Each key includes two long numbers that are used for encryption and, in the case of Secure Boot, for data authentication.

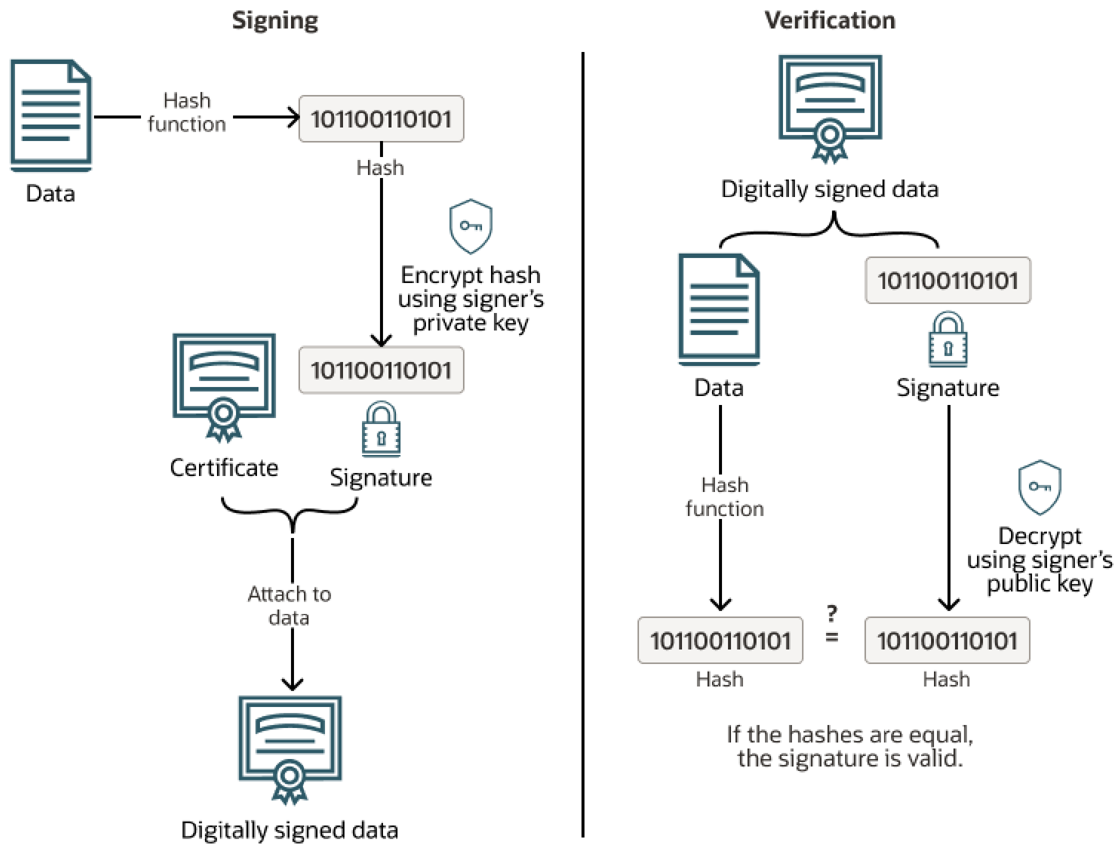
Secure Boot uses a private key and a public key.

- The *private key* is used to sign a file, which is an EFI program. That signature is then appended to the program.
- The *public key* must be publicly available. For Secure Boot, this key is embedded in the firmware itself or is stored in NVRAM. You can use the public key along with the signature to verify that the file was signed with that public key and that the file hasn't been changed.

For more information about PKI, see Oracle Linux: Managing Certificates and Public Key Infrastructure.

The following figure illustrates Secure Boot's key signing and verification process.

Figure 1-2 Secure Boot Key Signing and Verification Process



The data is signed with a private key. This process generates a hash of the data and uses the signer's private key to encrypt the hash. When the data needs validation, the signer's public key is used to decrypt the signature to obtain the hash of the data that was signed. The hash of the data is generated and compared with the hash that was decrypted from the signature. A match between the hashes indicates that the data is unchanged from when the was signed.

Although UEFI specification handles several key types, the X.509 key is commonly used. X.509 is a standard format for public key certificates and digital documents that securely associate cryptographic key pairs with identities, individuals, and organizations. The platform key (PK) must be an X.509 key. The X.509 key is stored in DER (Distinguished Encoding Rules) format. The DER key can be base64 encoded and stored as text in a PEM file.

The X.509 certificate includes a public key, a digital signature, and information about the identity that's associated with the certificate and its issuing certificate authority (CA). The public key and a private key form a key pair. The private key is kept secure, while the public key is included in the certificate. With the key pair, the owner of the private key can digitally sign documents that can be verified by anyone with the corresponding public key. By using the key pair, third parties can send messages that are encrypted with the public key that only be decrypted by the owner of the private key.

Note:

UEFI specifications use the terms *key* and *public key* to mean the public part of the key pair, or the X.509 certificate. However, in OpenSSL, the term *key* is the private key that's used for signing. Thus, all Secure Boot keys must be X.509 keys and *not* OpenSSL keys.

More recent kernel images use the PKCS#7 key type. PKCS (Public Key Cryptography Standards) is a set of standards for the generation and verification of digital signatures and certificates. PKCS#7 is a method of storing signed or encrypted data, including X.509 certificates. This point can be confusing because the key that's stored within a PKCS#7 structured DER or PEM formatted file is still an X.509 key. However, the type, and therefore the expected format when processing the file, is different. You must be aware of this distinction when signing kernel modules because the correct tool must be used when you perform the signing operation.

Four types of Secure Boot keys are built into the firmware. However, a fifth key can be used by the Secure Boot Shim, while a sixth key can be built into the Oracle Linux kernel image:

Platform Key (PK)
This is the top level key type that's used in Secure Boot. The PK offers complete control of the secure boot key hierarchy. The holder of the PK can install a new PK and update the Key Encryption Key (KEK). UEFI Secure Boot handles a single PK that's typically provided by the motherboard manufacturer. Thus, only the motherboard manufacturer has complete control over the system. You can control the Secure Boot process by replacing the PK with a version that you generate yourself.

Key Exchange Key (KEK)
The KEK signs keys so that the firmware accepts those keys as valid when entering them into the database. Without the KEK, the firmware can't detect whether a new key is valid or has been introduced by malware. If the KEK was absent, Secure Boot would require that the databases remain static. However, because the DBX is a critical element of Secure Boot, a static database would be unworkable. Hardware often ships with two KEKs: one from Microsoft and one from the motherboard manufacturer. Thus, either party can issue KEK updates.

UEFI Secure Boot Database Key (DB)
The DB key is important to Secure Boot because this key is used to sign or verify the binaries that you run, such as boot loaders, boot managers, shells, drivers, and so on. Most hardware is shipped with two Microsoft keys installed, one for Microsoft's use and the other for signing third-party software, such as Shim. Some hardware is also shipped with keys that are created by the computer manufacturer or other parties. Note that the database can hold several keys, for different purposes. Moreover, the database can contain both public keys that are matched to private keys, which can be used to sign several binaries, and hashes that describe individual binaries.

Forbidden Signature Database Key (DBX)
Contains keys and hashes that correspond to known malware or other unwanted software. If a binary matches a key or hash that's in both the UEFI Secure Boot key database and the DBX, the DBX takes precedence. This facility prevents the use of a single binary even if the binary is signed by a key that you don't want to revoke because it has been used before to sign several legitimate binaries.

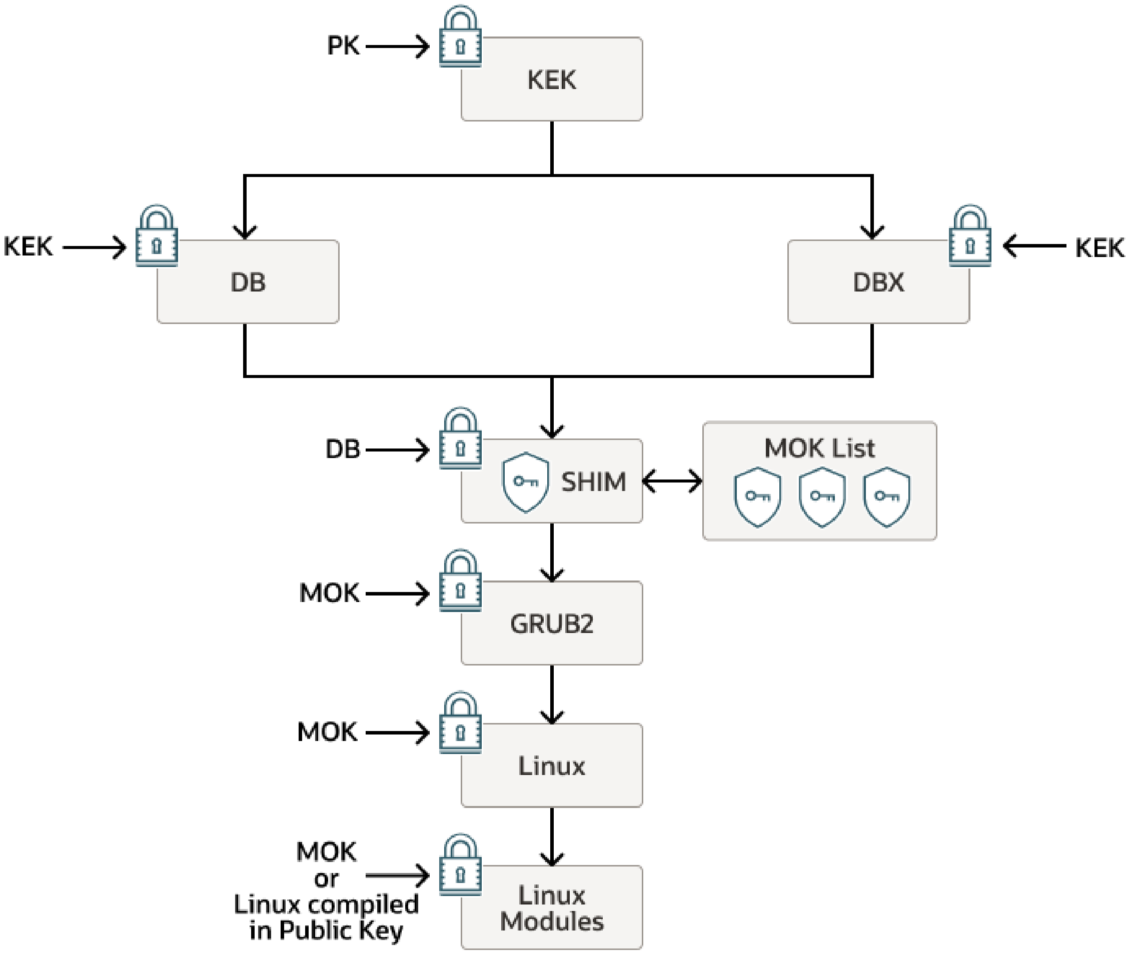
Machine Owner Key (MOK)
Similar to DBX, this key type signs boot loaders and other EFI executables and can also be used to store hashes that correspond to individual programs. MOKs aren't a standard part of Secure Boot. However, they're used by the Shim and PreLoader programs to store keys and hashes. The MOK facility is an ideal way to test newly generated key pairs and the kernel modules that are signed with them. MOK keys are stored in the MOK database. See About the MOK Database.

Public Key in the kernel
These keys can be built into the OS and they check signatures as kernel modules are loaded. Normally, when the `CONFIG_MODULE_SIG_KEY` parameter is unchanged from the default and a key pair doesn't already exist, the kernel build automatically generates a new key pair by using OpenSSL. Then, when `vmlinux` is built, the public key is built into the kernel.

Description of the Secure Boot Key Implementation

The following figure shows how the Secure Boot key implementation works in Oracle Linux.

Secure Boot Key Implementation



At the UEFI firmware level, the Platform Key (PK) is used to validate the Key Exchange Key (KEK), which is in turn used to validate all Database Keys (DB) and all DBX Keys (DBX). The DB keys are used with the DBX keys to validate the key used to sign the Shim binary. After the Shim is validated, keys stored within the MOK list and loaded by the Shim can be trusted to perform validation for the later loading operations that follow. The GRUB2 secondary bootloader is validated by using a key within the MOK list and by the MokListX that contains the forbidden MOK keys. Similarly, before the kernel is loaded, validation of the kernel image binary is first performed against the keys in the MOK list. Finally, after the kernel is loaded, the Linux kernel modules or Linux kernel images that are used for `kexec` operations can be validated, either against the MOK list or against any public keys that are compiled directly into the Linux kernel.

Description of the Shim First Stage Boot Loader

Shim is a basic software package that's designed to work as a first-stage boot loader on UEFI-based systems.

Systems that can use UEFI Secure boot typically ship with the following two keys:

- Microsoft Windows Production PCA 2011
- Microsoft Corporation UEFI CA 2011

When Secure Boot is enabled on the system, only those programs that are signed with either of these keys can boot. For the Shim first stage boot loader, Oracle uses a process that's agreed upon with Microsoft to sign Oracle's version of Shim with the Microsoft Corporation UEFI CA 2011 CA key. Embedded certificates within the Oracle shim validate the signed second stage boot loader and the kernel. See Description of the Secure Boot Key Implementation.

How Secure Boot Is Enforced Within Oracle Linux

The enforcement of Secure Boot within Oracle Linux includes certain restrictions, most of which are implemented to prevent Oracle Linux from being used as a boot loader through the `kexec` tool, which would break the Secure Boot chain of trust. The restrictions, which are referred to as *lockdown*, prevent access to Ring-0 when Secure Boot is enabled, even by the `root` user.

The following are details of the how Secure Boot is enforced in Oracle Linux 10 kernel releases:

Unbreakable Enterprise Kernel (UEK)
The UEK uses the Kernel Lockdown feature. This feature prevents both direct and indirect access to a running kernel image, which protects the kernel image from unauthorized modifications. It also prevents access to the security and cryptographic data in the kernel's memory.
Lockdown restrictions are applied using three different modes:

- **none**: No restrictions apply.
- **integrity**: Disables kernel features that let user space edit the running kernel. This mode is automatically enabled when Secure Boot is enabled in UEK.
- **confidentiality**: Also disables kernel features that enable user space to extract confidential information from the kernel.

Red Hat Compatible Kernel (RHCK)
When Secure Boot is enabled in Oracle Linux 10 with RHCK, the kernel is automatically put into Lockdown mode. This restricts certain kernel capabilities that could be used to perform unauthorized modification of the kernel.

Enabling and Disabling Secure Boot

You can enable and disable Secure Boot by accessing the system's UEFI setup program. For instructions on enabling and disabling Secure Boot through the UEFI setup program for specific hardware, see the manufacturer's instructions.

Note that if you're having trouble working with the system UEFI, you can disable any further validation for Secure Boot at the level of the Shim. Although you can disable further validation for Secure Boot from user space, you still need physical access to the system at boot so that you can access the MokManager utility when the Shim loads. For more information, see Disabling Secure Boot at Shim Level.

About the MOK Database

MOK keys are stored in the MOK database, or "MOK list." Add certificates for custom built kernels or kernel modules to the MOK database if the keys that are used to sign those components or the CA certificate for those keys aren't present in the UEFI Secure Boot key database. You can add these keys without requiring that a key chains back to another key that's already in the KEK database. When a key is in the MOK database, it's automatically propagated to the system key ring on every boot when UEFI Secure Boot is enabled.

To enroll a MOK key, you must manually do so on each target system by using the MOK Manager Utility on the UEFI system console.

You can also use the MOK Forbidden Signature Database (MOKx), which is similar to the DBX. MOKx features let a user prevent a specific kernel or kernel module from being loaded, as identified by that component's public key or the signature. The MOKx also forbids any second stage boot loader or binary from being booted by Shim, similar to GRUB2's provided file paths `grub2, fwupd, mmx64, mmaa64,` and `etc`.

You can use the MOK database to insert keys into the UEFI Shim's trusted keys directly from user space. This is easier than manually adding keys to the UEFI Secure Boot Key Database, which is another option. However, with the MOK database approach, the instructions aren't tied to particular hardware and you don't have to copy keys somewhere that's accessible to UEFI.

The tool to manage the MOK database is the `mokutil` utility, with which you access the MOK Manager. See About the mokutil Utility.

About the Machine Keyring

The machine keyring is a special kernel keyring introduced in UEK R7. It stores certificates and public keys relevant to secure boot processes and is accessible to the kernel and system-level services for secure verification of kernel modules and binaries. Certificates loaded into the machine keyring ensure that signatures can be validated during the secure boot sequence, complementing the key management performed by firmware-level UEFI databases. Using the machine keyring upholds system integrity and compliance within the secure boot framework.

The default Machine Owner Key (MOK) certificates embedded in the shim bootloader are automatically added to the machine keyring during boot. This mechanism lets the kernel verify signatures from trusted sources as part of secure boot.

2

Tools and Applications for Administering Secure Boot

This chapter provides a basic summary of the tools and applications that you can use to administer Secure Boot in Oracle Linux.

About the pesign Tool

The pesign tool is a command line tool for manipulating signatures and cryptographic digests of UEFI applications. You can use the pesign tool to sign kernels for both GRUB2 and Shim.

You can also use the pesign tool for printing binary signature information. The pesign package also provides the pesigcheck tool that you can use to verify a signature against an exact public certificate.

The pesign tool accepts the X.509 certificate/key pair and signs a PE-COFF binary with it. The Oracle Linux kernel has an EFI boot stub that wraps the bzImage file as a PE-COFF binary according to standard UEFI implementation. This implementation provides you with the option to boot the kernel directly from UEFI without requiring a boot loader. In addition, the pesign tool can perform the required signing. See About Secure Boot Keys.

Typically, you use the pesign tool to perform one of the following tasks:

- Sign a kernel image with a custom key that you created to sign custom kernel modules. See Signing Kernel Images and Kernel Modules for Use With Secure Boot.
- Enroll the hash for a particular kernel within the MOK database so that the kernel can be loaded at boot, even if the Shim doesn't contain its certificate.
- Extract a kernel hash from the signed kernel binary so that you can enroll it by using the mokutil tool. See Enrolling a Kernel Hash in the MOK Database.

About the efibootmgr Application

Oracle Linux provides the efibootmgr user space application that you can use to change the Intel Extensible Firmware Interface (EFI) Boot Manager. You use the application to perform several tasks, including the following:

- Create and destroy boot entries.
- Change the boot order.
- Change the next running boot option.

This tool is a general usage application and doesn't directly relate to Secure Boot. However, the tool helps you to manage UEFI boot options directly from user space and makes it easier to debug and resolve some UEFI boot issues from the command line. For more information and examples, see the efibootmgr(8) manual page.

About the mokutil Utility

Shim lets users control their own systems. The distribution vendor key is built into the Shim binary itself. However, an extra database with keys, called the Machine Owner Key (MOK) list or database, is also provided, and which the user can manage through the MOK Manager Utility.

In Oracle Linux, the MokManager utility is installed in the EFI System Partition (ESP) within the `/boot/efi/EFI/redhat` directory. Originally called `MokManager.efi`, this file has been renamed to `mmx64.efi` for x86_64 platforms or `mmaa64.efi` for Arm platforms. MOK keys can be placed in the ESP and then installed from MokManager during boot.

By running the `mokutil` command, you can use the MokManager utility to add and remove keys in the MOK list, which remain separate from the distribution vendor key. The `mokutil` utility lets you to make keys available to the MOK database directly from user space by using the command line. Because keys are often created or extracted in this space, `mokutil` is the most appropriate tool to use for managing keys that are used for Secure Boot.

Note that although `mokutil` is run from user space, it doesn't update the MOK database directly. Instead, `mokutil` makes keys available to the MOK Management service and triggers the Shim to display the MOK Management menu at boot. This process ensures that keys or hashes are only enrolled within the MOK database by somebody who has physical access to the system and prevents a malicious application or user from changing the MOK database directly from user space.

Typical use case scenarios where you might use the `mokutil` utility include the following:

- Adding keys for custom modules that aren't included and signed with the distribution and which you needed to sign yourself. See Signing Kernel Images and Kernel Modules for Use With Secure Boot.
- Adding keys or hashes for custom kernels for which the signing key is either revoked or you have built from source. See Use mokutil to Update Signature Keys for UEFI Secure Boot.
- Disabling Secure Boot operations from the Shim upward. See Disabling Secure Boot at Shim Level.

For more information, see the `mokutil(1)` manual page.

Disabling Secure Boot at Shim Level

UEFI can be disabled through the UEFI setup program, or you can use the `mokutil` utility to disable Secure Boot at the level of the Shim, as described here.

When you disable Secure Boot at Shim level, UEFI Secure Boot remains enabled but no further validation takes place after the Shim is loaded.

The following steps apply to OS that are loaded through Shim and GRUB:

1. Disable Secure Boot.

   Run the following command to disable Secure Boot at the Shim level:

   ```
   sudo mokutil --disable-validation
   ```

2. Select a password

Select a password that's between 8 and 16 characters and then enter the same password to confirm.

3. Reboot the system.
4. Perform MOK management.

   When prompted, press a key to perform MOK management.
5. Change the Secure Boot state.

   Select the **Change Secure Boot state** option.
6. Confirm the change.

   When promoted, enter each character of the password that you chose, to confirm the change. Press Return (or Enter) after each character.
7. Reboot

   Select Yes, then select Reboot to reboot the system.

To reenable the Secure Boot state at the Shim level, run the following command:

```
sudo mokutil --enable-validation
```

Follow the same prompts that appear in the procedure for disabling Secure Boot.

Validating SBAT Status

Oracle Linux10 uses UEFI Secure Boot Advanced Targeting (SBAT), available in the `shim` package.

SBAT is a mechanism for revoking older versions of core boot components such as `grub2` and `shim` by setting generation numbers in the `.sbat` section of the UEFI binary. The generation number set in a UEFI binary defines its revocation level.

To confirm whether UEFI Secure Boot is active, use the `--sb-state` option with the `mokutil` command:

```
mokutil --sb-state
```

The`mokutil` utility can be used to review and update UEFI SBAT revocation status. To review the current UEFI SBAT level on which the current system is running, use the `--list-sbat-revocations` option:

```
mokutil --list-sbat-revocations
```

You can change the SBAT policy that applies at the next reboot. Setting the SBAT policy to `latest` applies the latest SBAT revocations and prevents the system from booting older `grub2` and `shim` packages that were operating at an earlier SBAT level, and `previous` falls back to the previous SBAT revocation level:

```
mokutil --set-sbat-policy latest
```

```
mokutil --set-sbat-policy previous
```

For systems with UEFI Secure Boot enabled, the default SBAT policy is `previous`. Both the `latest` and `previous` SBAT policies only set a revocation level that's the same or later than it was when the latest `shim` package was installed.

For troubleshooting purposes, you can reset the SBAT policy to the default revocation level. First, disable UEFI Secure Boot and then set the `delete` SBAT policy:

```
mokutil --set-sbat-policy delete
```

> **Note:**
>
> You can review the `.sbat` metadata used by `grub2` and `shim` by using the `objdump` command. For example, on an x86_64 system you can run the following commands:
>
> ```
> objdump -s -j .sbat grubx64.efi
> ```
>
> ```
> objdump -s -j .sbat shimx64.efi
> ```
>
> To review the current SBAT policy levels for the provided shim:
>
> ```
> objdump -s -j .sbatlevel shimx64.efi
> ```

About the dbxtool Command

The `dbxtool` command combines a command line tool with the `systemd` service that's used to apply UEFI Secure Boot DBX updates. With this tool, you can operate on the UEFI Forbidden Signature Database, also known as the DBX revocation list. For example, you can use the command to list the current DBX contents and update them to a newer version.

UEFI DBX files are available at https://uefi.org/revocationlistfile. The DBX prevents any software that's signed using a compromised key from loading. In this way it helps to protect the integrity of the Secure Boot framework and avoids needing to manually manage a static database of keys.

The most current UEFI DBX files and the `dbxtool` utility that's used to manage the DBX revocation list are in the `fwdup` package and updates are present within each later release of this package on the Oracle Linux yum server. The DBX files are prefixed by `DBXUpdate` and found in the `/usr/share/fwupd/remotes.d/vendor/firmware/` directory.

If the `dbxtool systemd` service is running, DBX updates are handled automatically. However, if you're notified of a CVE that requires a DBX update, you might need to use the tool manually.

3

Signing Kernel Images and Kernel Modules for Use With Secure Boot

This chapter provides instructions on signing kernel modules for Secure Boot.

> **NOT_SUPPORTED:**
>
> Oracle doesn't support any modules that are built from source directly outside of Oracle's official release mechanisms. For help with these modules, contact the hardware vendor.

A system in Secure Boot mode only loads boot loaders and kernels that have been signed by Oracle. However, you might need to build and install a third-party module to enable specific hardware on a deployed system. If you still require UEFI Secure Boot, the module must be signed with a key that can be validated against a certificate within the UEFI Secure Boot key database or within the MOK database so that the module is recognized at boot.

> **Important:**
>
> Using the MOK utility on a server depends on server firmware implementation and configuration. Check that the server provides this capability before manually updating signature keys used for UEFI Secure Boot. If you're unsure, don't follow the instructions provided here.
>
> Adding certificates to the MOK database by using the MOK utility requires that you have physical access to the system so that you can complete the enrollment request after the Shim is loaded by UEFI. Don't follow the instructions in this document if you have no physical access to the system.

Because of differences in kernel releases, instructions on how to sign modules differ depending on the kernel version on the system. In particular, the key signature type within the module signature has changed from X.509 to PKCS#7. Therefore, although the process to sign the module by using the kernel-provided `sign-file` utility is still used, you might be required to use a utility more appropriate to the specific kernel for which a module is being signed.

Requirements for Signing Kernel Images and Kernel Modules

Before you can sign a module, you must install several required packages, including the kernel source for the kernel where the module is loaded. You also require a signing certificate for a key pair that you have created for this purpose.

Signing kernel images and kernel modules have the following requirements:

- Installation of required pacakges

- Creation of signing certificates

Installing Required Packages

You need only a standard minimal installation of the latest Oracle Linux 10 release for this procedure. The steps assume that the system is using UEK as the operating environment.

1. Install the required kernel packages.

   Obtain the package that contains the system's kernel source:

   ```
   sudo dnf install kernel-uek-devel
   ```

   > **Note:**
   >
   > If you're using RHCK, the kernel source is in the *kernel-devel* package.

2. Update the system.

   Update the system to ensure that you have the most recent kernel and related packages:

   ```
   sudo dnf update
   ```

3. Reboot the system.

   This step is in case the kernel is included in the system update. By rebooting, you avoid confusion around the kernel version that you're working with and the kernel running on the system when you begin kernel-signing operations.

4. Install the module signing utilities.

   Install the required utilities for performing module signing operations.

   ```
   sudo dnf install openssl keyutils mokutil pesign
   ```

5. (Optional) install build tools.

   If you need to build modules from source, you might install the `Development Tools` group to ensure that build tools are available, for example:

   ```
   sudo dnf group install "Development Tools"
   ```

Generating a Signing Certificate

If you don't already have a signing certificate to be used for signing third-party modules or kernel images, you can generate one by using the OpenSSL utilities. For more information about OpenSSL and the public key infrastructure, see Oracle Linux: Managing Certificates and Public Key Infrastructure.

1. Create a configuration file that OpenSSL can use to obtain default values when generating certificates.

As best practice, create the file in `/etc/ssl/x509.conf` with the rest of the OpenSSL configuration. The following is an example of the configuration file:

```
[ req ]
default_bits = 4096
distinguished_name = req_distinguished_name
prompt = no
string_mask = utf8only
x509_extensions = extensions

[ req_distinguished_name ]
O = Module Signing Example
CN = Module Signing Example Key
emailAddress = first.last@example.com

[ extensions ]
basicConstraints=critical,CA:TRUE
keyUsage=digitalSignature
extendedKeyUsage = codeSigning
subjectKeyIdentifier=hash
authorityKeyIdentifier=keyid:always
```

2. Generate a new key pair from the configuration file.

   For example, the following command creates a signing certificate that's valid for 10 years (3,650 days).

   ```
   sudo openssl req -x509 -new -nodes -utf8 -sha512 -days 3650 -batch -
   config /etc/ssl/x509.conf -outform DER -out /etc/ssl/certs/pubkey.der -
   keyout /etc/ssl/certs/priv.key
   ```

   Ensure that the keys are adequately protected.

3. Export the certificate in PEM format.

   Enter the following command to export the certificate as a `.pem` file:

   ```
   sudo openssl x509 -inform DER -in /etc/ssl/certs/pubkey.der -out /etc/ssl/
   certs/pubkey.pem
   ```

Signing the Kernel for Secure Boot

UEFI Secure Boot requires that kernels are signed with a trusted certificate to prevent attackers from installing and running unauthorized OSs.

Oracle signs kernel releases that are provided through official software channels to verify their origin and integrity. For a custom kernel to perform the `boot` or `kexec` operations, you must sign the kernel image by using the signing certificate that you created and confirm that you trust kernel images that are signed with that certificate.

Signing the kernel for Secure Boot involves the following tasks:

1. Configuring an NSS Database
2. Signing the Kernel Image
3. Updating the MOK Database

Configuring an NSS Database

The NSS database stores complete sets of keys that the tool for signing kernels accesses to obtain the kernel signing key.

1. Configure an NSS database.

   Run the following command to create a certificate and key database in the current directory.

   ```
   sudo certutil -d . -N
   ```

2. Create a password for the database as prompted.
3. Export a PKCS#12 version of the kernel signing key.

   NSS utilities are only capable of working with PKCS#12 formatted key files, so you need to perform this step so that you can sign the kernel image.

   ```
   sudo openssl pkcs12 -export -inkey /etc/ssl/certs/priv.key -in /etc/ssl/
   certs/pubkey.pem -name cert -out /etc/ssl/certs/cert.p12
   ```

4. Enter the export password as prompted.

   The password refers to the password for the PKCS#12 archive. For convenience, make this password match the password for the NSS database.

5. Add or import the PKCS#12 version of the kernel signing key.

   Enter the following command to import the kernel signing key to the new database.

   ```
   sudo pk12util -d . -i cert.p12
   ```

6. Enter the passwords as prompted.

   Two password prompts are displayed: first, for the NSS database, then for the PKCS#12 archive.

   ```
   Enter Password or Pin for "NSS Certificate DB":
   Enter password for PKCS12 file:
   pk12util: PKCS12 IMPORT SUCCESSFUL
   ```

Signing the Kernel Image

In this task, you use the `pesign` utility to sign the kernel with a new signature using the signing key in the NSS database.

1. Remove the existing PE signature.

   Enter the following command:

   ```
   sudo pesign -u 0 -i /boot/vmlinuz-$(uname -r) --remove-signature -o
   vmlinuz.unsigned
   ```

2. Assign a new signature.

Assign a new signature based on the kernel signing key in the NSS database:

```
sudo pesign -n . -c cert -i vmlinuz.unsigned -o vmlinuz.signed -s
```

3. Enter the password as prompted.

   The password of the NSS certificate database is the one that you created in Configuring an NSS Database.

4. Copy the signed kernel back to the `/boot` directory.

   The following command performs the copy operation. The `-b` option in the command creates a backup of the original kernel image.

   ```
   sudo cp -bf vmlinuz.signed /boot/vmlinuz-$(uname -r)
   ```

Updating the MOK Database

Because the key that you created isn't included in the UEFI Secure Boot Key Database, you must enroll it into the MOK database in the Shim.

> **Note:**
>
> If you only want to let a specific kernel or kernel module load under Secure Boot, and you don't want to enroll a certificate, you can enroll the hash of the binary instead. This limits authorizations to the specific binary, rather than all components signed by a particular certificate. This process is described in Enrolling a Kernel Hash in the MOK Database.

1. Import the key.

   Import the key with the following command:

   ```
   sudo mokutil --import /etc/ssl/certs/pubkey.der
   ```

   The command prompts you for a single-use password that you use when the MOK Management service enrolls the key after you reboot the system.

2. Reboot the system.

   The UEFI Shim automatically starts the `Shim UEFI key manager` at boot. Ensure that you hit a key within 10 seconds to interrupt the boot process to enroll the MOK key you created.

3. Press any key to perform MOK Management.
4. Select `Enroll MOK` from the menu.
5. Select `View key 0` from the menu to display the key details.
6. Check and confirm.

   Verify that the values presented match the key that you used to sign the module and that you inserted into the kernel image, then press any key to return to the `Enroll MOK` menu.

7. Select `Continue` from the menu.

The `Enroll the key(s)?` screen is displayed.

8. Select `Yes` to enroll the key.
9. Enter the password

   At the password prompt, enter the password that you used when you imported the key at the beginning of this procedure.

   The key is enrolled within the UEFI Secure Boot key database.
10. Reboot the system.

    When the `Perform MOK management` screen is displayed, select `Reboot` from the menu.

Enrolling a Kernel Hash in the MOK Database

Describes how to enroll a specific kernel's hash into the MOK database.

If you can't or don't want to enroll a signing certificate as described in Updating the MOK Database, you can enroll a specific kernel’s hash into the MOK database. This lets you load that particular kernel under Secure Boot, even without a certificate.

1. Extract the kernel's hash.

   Use the `pesign` tool to obtain the hash signature for a kernel. For example, to obtain the hash of the running kernel:

   ```
   pesign -h -i /boot/vmlinuz-$(uname -r)  | awk '{print $1}' > vmlinuz.hash
   ```

   > **Note:**
   >
   > The `pesign` tool returns a hash value and the path to the kernel module. In version 116 of the `pesign` tool packaged with Oracle Linux 10, the fields are returned in a different order to earlier versions.

2. Enroll the hash using `mokutil`.

   ```
   sudo mokutil --import-hash vmlinuz.hash
   ```

   You're prompted to set a one-time password. Remember this, because you're asked for it when the system reboots.
3. Reboot the system.
4. At boot, use the MOK Manager to enroll the hash.

   From the MOK Manager menu, select the "Enroll hash" option, enter the password, and confirm.

Signing the Kernel Module for Secure Boot

UEFI Secure Boot requires that kernel modules are signed with a trusted certificate to prevent attackers from installing and running unauthorized OS and malicious drivers.

Oracle signs kernel releases that are provided through official software channels to verify their origin and integrity. However, to install other drivers, you must create signing certificates for them, sign the relevant kernel modules, and confirm that you trust the kernel modules that are signed with that certificate.

UEFI Secure Boot trusts modules that are signed using platform certificates that are available in the UEFI and MOK databases. The key for signing the module is enrolled into the database.

Signing the kernel module involves the following tasks:

1. Signing the Kernel Module
2. Updating the MOK Database with the Kernel Module Certificate

Signing the Kernel Module

The `sign-file` utility ensures that the module is signed correctly for the kernel. This utility is provided within the kernel source.

1. Ensure that module is already installed in `/lib/modules/`.
2. Run the `sign-file` utility for the running kernel.

   Enter the following command to sign the module.

   ```
   sudo /usr/src/kernels/$(uname -r)/scripts/sign-file sha512 /etc/ssl/certs/
   priv.key /etc/ssl/certs/pubkey.der /lib/modules/$(uname -r)/path/to/
   module.ko
   ```

3. (Optional) Check the signature information of the module.

   Use the `modinfo` command to check the signature information. The syntax is:

   ```
   modinfo module
   ```

   For example, a module named `hello` might display the following output:

   ```
   filename: /lib/modules/6.12.0-0.20.20.el10uek.x86_64/extra/
   hello.ko
   description:    Hello World Linux Kernel Module
   author:         A.Developer
   license:        GPL
   srcversion:     D51FB4CF0B86314953EE797
   depends:
   retpoline:      Y
   name:           hello
   vermagic:       6.12.0-0.20.20.el10uek.x86_64 SMP mod_unload modversions
   sig_id:         PKCS#7
   signer:         Module Signing Example Key
   sig_key:        AB:2C:E3:AB:87:D9:9C:6A:31:B8:80:20:D4:92:25:F3:9A:26:DC
   sig_hashalgo:   sha512
   signature:
   9F:B0:25:CB:14:C1:C7:10:7F:60:1E:E6:66:82:64:58:91:1F:01:A5:

   D9:03:1B:9C:2D:42:00:45:78:2B:FA:70:F8:C7:3B:1A:A2:42:00:09:

   33:E0:81:1D:C6:E6:46:A5:FE:8B:9F:8C:3D:4E:A1:3A:05:52:ED:F6:

   25:F9:88:98:D3:70:78:1D:7E:63:F3:73:C8:C8:14:C2:3A:52:B4:8F:
   ```

```
4C:8D:80:D9:0D:24:F8:C9:B1:28:82:B6:A9:27:56:C6:86:80:25:A5:
75:C8:78:A9:30:BD:01:4C:DD:43:7F:FD:41:98:2C:59:21:7D:39:17:
EC:2C:C1:65:1D:95:F0:09:C7:F6:45:10:83:15:78:A2:EE:D4:73:79:
B2:F0:57:C1:96:B3:4C:43:B8:D1:87:94:50:61:D6:EC:50:2B:6A:6C:
5C:C1:3E:8C:CB:6F:19:DC:EF:6C:12:07:03:99:B7:B3:22:0B:F6:AC:
CB:40:C6:34:15:EA:1F:88:D4:4E:1C:87:2D:5A:92:F7:12:A6:E7:91:
B3:80:AA:80:8F:49:B7:F0:F0:97:05:09:7A:65:30:4A:AE:10:BE:9F:
6A:E4:B2:24:BE:1A:21:D0:F6:15:05:DA:2C:64:EA:B2:8E:AC:6F:18:
40:65:21:F6:AA:17:31:AE:3F:3A:43:DB:A8:BC:71:79:EF:11:18:DE:
86:EE:74:2A:E0:44:FC:B3:FF:CB:CB:F0:CA:BD:7B:A1:57:84:D8:A6:
91:E5:B8:EF:1B:8A:63:16:43:03:AF:C4:C7:BF:52:9A:A9:23:75:C6:
42:54:69:4E:3D:51:56:5A:9D:9B:C7:11:5E:9A:30:87:5F:F3:5E:C3:
AE:2C:1D:6F:C9:4D:15:E5:CF:EC:46:0E:EF:D9:BB:2F:DF:DF:54:EA:
F3:B6:9C:A3:6F:80:19:B9:DF:FA:2A:30:4E:2E:70:74:11:F9:5C:F6:
EE:1A:DF:86:C4:2B:36:7E:B4:A4:D4:7E:30:19:1A:D1:92:D3:A7:FB:
53:BF:67:C3:65:9E:4B:92:F0:6C:D4:6C:05:9B:0F:BF:D1:5B:CB:86:
AE:68:00:AE:43:53:8B:7D:7E:18:20:CD:65:68:6C:4A:0D:93:A4:54:
09:39:9C:D3:BD:CD:17:B6:8A:D3:62:0C:CA:A8:FD:1A:52:CE:29:A0:
93:BF:AD:D2:58:3F:EA:4E:4B:50:31:6F:F6:B2:1E:87:C4:0A:9D:E4:
43:E9:C7:CA:E9:CB:EF:A6:61:5B:DA:01:33:37:66:DB:16:8D:7C:D7:
30:39:57:D4:0C:1A:54:AE:91:7B:FE:35:10:CC:34:03:99:EA:5A:57:
                E0:95:61:02:42:95:A2:F5:2E:72:30:95
```

Updating the MOK Database with the Kernel Module Certificate

Because the key that you created isn't included in the UEFI Secure Boot Key Database, you must enroll it into the MOK database in the Shim.

> **Note:**
>
> If you only want to a specific kernel or kernel module to run under Secure Boot, and you don't want to enroll a certificate, you can enroll the hash of the binary as described in Enrolling a Kernel Hash in the MOK Database. This limits authorizations to the specific binary, rather than all components signed by a certificate.

1. Import the key.

   Use the `mokutil` utility to import the key:

   ```
   sudo mokutil --import /etc/ssl/certs/pubkey.der
   ```

   The command prompts you for a single use password that you use when the MOK Management service enrolls the key after you reboot the system.
2. Reboot the system.

   The UEFI Shim automatically starts the `Shim UEFI key manager` at boot. Ensure that you hit a key within 10 seconds to interrupt the boot process to enroll the MOK key you created.
3. Press any key to perform MOK Management.
4. Select `Enroll MOK` from the menu.
5. Select `View key 0` from the menu to display the key details.
6. Check and confirm the key values.

   Verify that the values presented match the key that you used to sign the module and that you inserted into the kernel image, then press any key to return to the `Enroll MOK` menu.
7. Select `Continue` from the menu.

   The `Enroll the key(s)?` screen is displayed.
8. Select `Yes` to enroll the key.
9. Enter the password.

   At the password prompt, enter the password that you used when you imported the key at the beginning of this procedure.

   The key is enrolled within the UEFI Secure Boot key database.
10. Reboot the system.

    When the `Perform MOK management` screen is displayed, select `Reboot` from the menu.

Validating That a Key Is Trusted

After the system is booted, you can validate whether a key is included in the appropriate kernel keyring. Validation depends on the kernel version that you're running. Also, the keyring name that you need to check varies, as the implementation has changed across kernel versions.

If the key that was generated for signing custom modules is listed within the correct keyring, you can load modules that are signed with this key while in Secure Boot mode.

UEK R8

The following describes how to validate a key in UEK R8.

The UEK R8 release provides the `.machine` keyring to enhance security. Keys in the `.machine` keyring are trusted by the Oracle Linux kernel. At system boot, all MOK keys are loaded into the `.machine` keyring.

The `.machine` keyring is linked to the `.secondary_trusted_keys` keyring. This linkage ensures that the `.machine` keyring is consulted whenever the kernel checks the `.secondary_trusted_keys` keyring to validate a signed kernel module.

In essence, when validating a signed kernel module, the kernel use the keys in the `.secondary_trusted_keys` keyring, which now also references the trusted keys in the `.machine` keyring, ensuring a comprehensive validation process. This is shown in the following example:

```
sudo keyctl show %:.secondary_trusted_keys


Keyring
 772746105 ---lswrv      0     0  keyring: .secondary_trusted_keys
 252396885 ---lswrv      0     0   \_ keyring: .builtin_trusted_keys
 660166481 ---lswrv      0     0   |   \_ asymmetric: Oracle CA Server:
702a35b0d12005e5010c0614f7b8abf7c5bd5f73
  86702374 ---lswrv      0     0   |   \_ asymmetric: Oracle IMA signing CA:
a2f28976a05984028f7d1a4904ae14e8e468e551
 247354640 ---lswrv      0     0   |   \_ asymmetric: Oracle America, Inc.:
Ksplice Kernel Module Signing Key: 09010ebef5545fa7c54b626ef518e077b5b1ee4c
 264616160 ---lswrv      0     0   |   \_ asymmetric: Oracle Linux Kernel
Module Signing Key: 2bb352412969a3653f0eb6021763408ebb9bb5ab
 772320403 ---lswrv      0     0   \_ keyring: .machine
 450491670 ---lswrv      0     0       \_ asymmetric: Oracle America, Inc.:
7c552922286d66bcb33c53d7ee0f1cd716ecdc63
 100307441 ---lswrv      0     0       \_ asymmetric: Oracle America, Inc.:
39bff3f0f578f26e527321cafda2a9cdbd71143c
 688922247 ---lswrv      0     0       \_ asymmetric: Oracle America, Inc.:
4ff35c3e09ce586fa776d56468d86b022af272f1
```

RHCK

The following describes how to validate a key for Red Hat Compatible Kernels (RHCK).

Keys within both the `builtin_trusted_keys` keyring and the `platform` keyring are trusted for both module signing and for the `kexec` tools. You can follow the standard procedure to sign a module and add it to the MOK database for the key to appear in the `platform` keyring. The keyring is then automatically trusted.

Because a key can be loaded into the `builtin_trusted_keys` keyring, check both keyrings for the module signing key, for example:

```
sudo keyctl show %:.builtin_trusted_keys


Keyring
        441234704 ---lswrv      0     0  keyring: .builtin_trusted_keys
        798307349 ---lswrv      0     0   \_ asymmetric: Oracle CA Server: 
32a7ceb6c56614c69b4729b455254bfaf09569a4
        277992501 ---lswrv      0     0   \_ asymmetric: Oracle Linux RHCK 
Module Signing Key: dd995b155c19b3a7c3ef7707b969e25f9639666e
        1000618915 ---lswrv     0     0   \_ asymmetric: Red Hat Enterprise 
Linux kpatch signing key: 4d38fd864ebe18c5f0b72e3852e2014c3a676fc8
        199403819 ---lswrv      0     0   \_ asymmetric: Red Hat Enterprise 
Linux Driver Update Program (key 3): bf57f3e87362bc7229d9f465321773dfd1f77a80


sudo keyctl show %:.platform


Keyring
        705628740 ---lswrv      0     0  keyring: .platform
        89698906 ---lswrv      0     0   \_ asymmetric: Microsoft Corporation 
UEFI CA 2011: 13adbf4309bd82709c8cd54f316ed522988a1bd4
        497244381 ---lswrv      0     0   \_ asymmetric: Oracle America, 
Inc.: d6ee3a06a222bf4244b8986a531046e59c14eeef
        710039804 ---lswrv      0     0   \_ asymmetric: Oracle America, 
Inc.: c65d1d746ae4cb127762e1dbd7ade48215703c5c
        730271863 ---lswrv      0     0   \_ asymmetric: Oracle America Inc.: 
2e7c1720d1c5df5254cc93d6decaa75e49620cf8
        535985802 ---lswrv      0     0   \_ asymmetric: Oracle America, 
Inc.: 795c5945e7cb2b6773b7797571413e3695062514
        607819007 ---lswrv      0     0   \_ asymmetric: Oracle America, 
Inc.: f9aec43f7480c408d681db3d6f19f54d6e396ff4
        99739320 ---lswrv      0     0   \_ asymmetric: Oracle America, Inc.: 
430c85cb8b531c3d7b8c44adfafc2e5d49bb89d4
        231916335 ---lswrv      0     0   \_ asymmetric: Microsoft Windows 
Production PCA 2011: a92902398e16c49778cd90f99e4f9ae17c55af53
        866576656 ---lswrv      0     0   \_ asymmetric: Oracle Linux Test 
Certificate: d30dffa37bec20ecfb1d3caee53cd746282e8cad
        230958440 ---lswrv      0     0   \_ asymmetric: Module Signing 
Example Key: a43b4e638874b0656db2bc26216f56c0ac39f72b
```