

# Encrypted AI Inferencing with Fully Homomorphic Encryption and IBM Hyper Protect

Session 2217

Lab Exercise Guide



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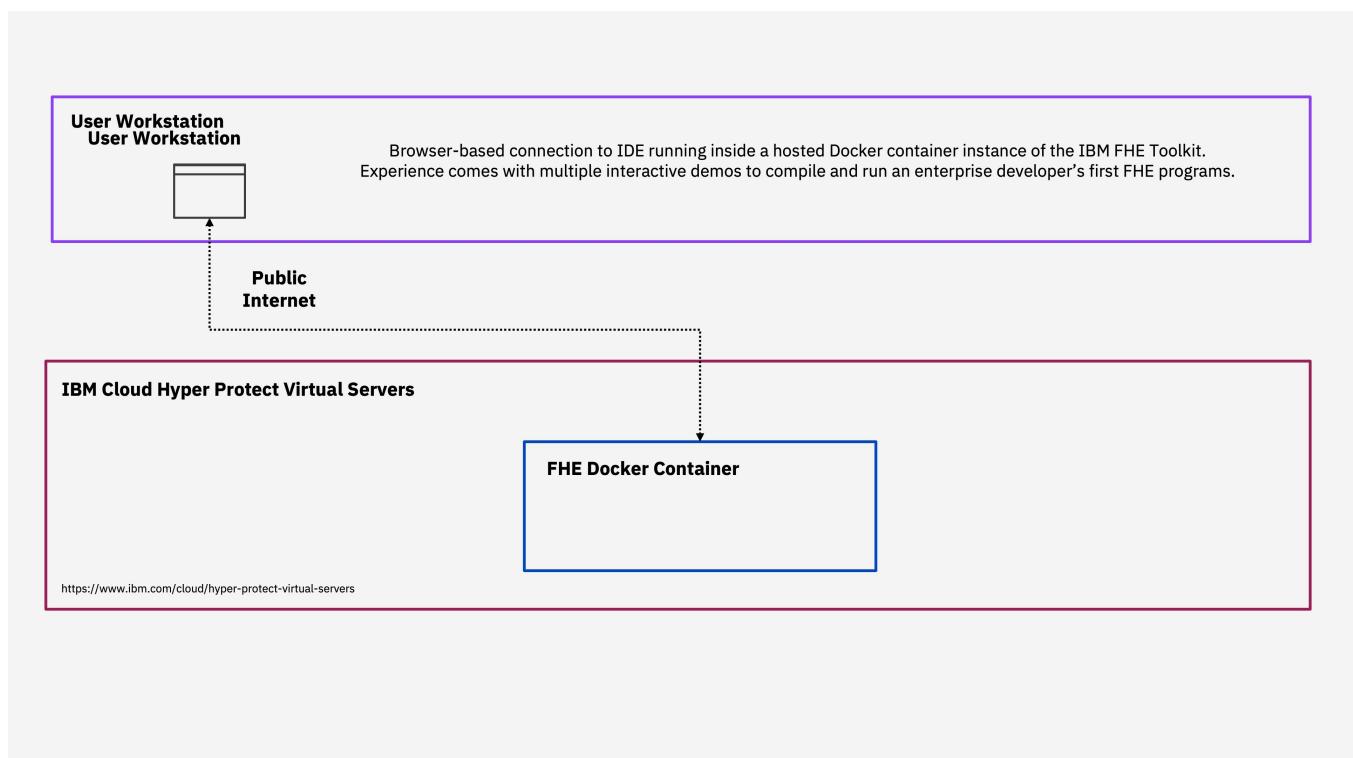
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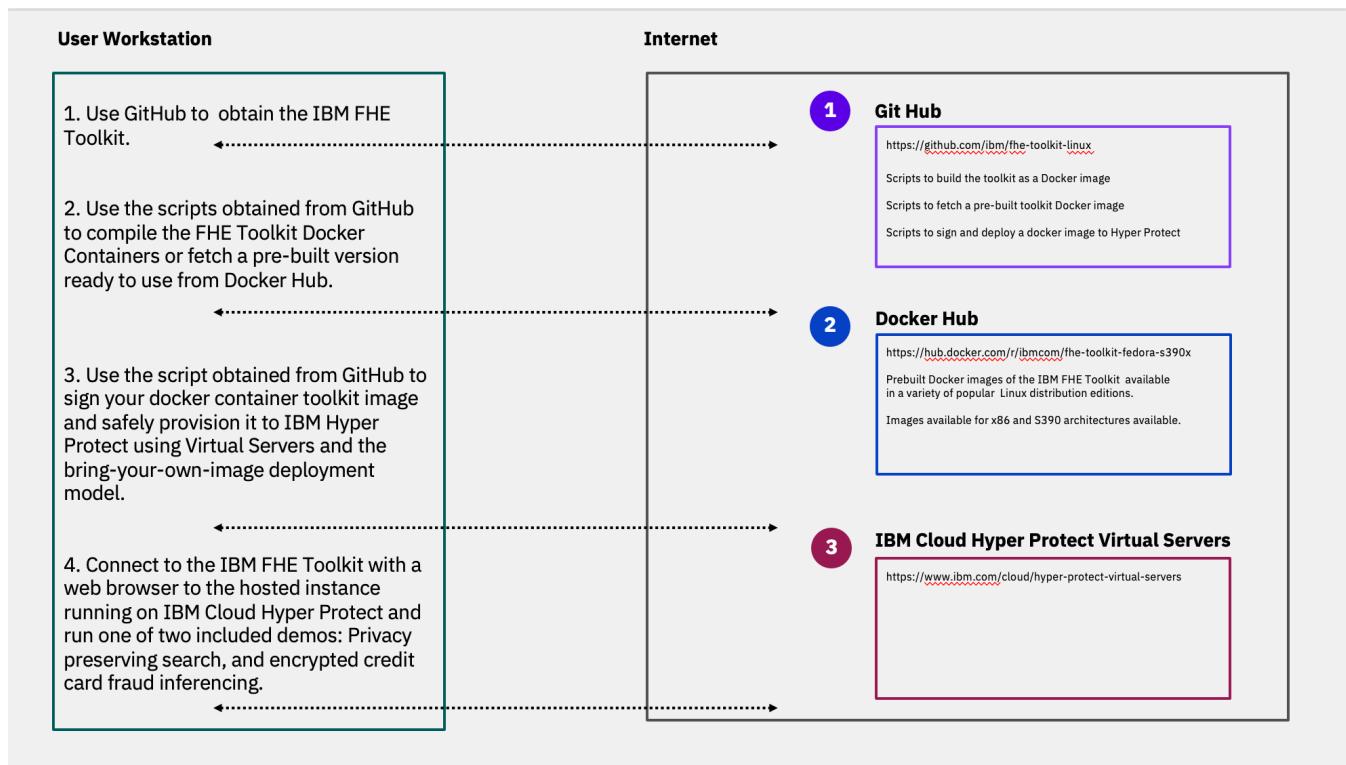
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# 1 Introduction

Fully Homomorphic Encryption (FHE) can help you achieve zero trust by unlocking the value of data without needing to decrypt it. If you are using the IBM FHE toolkit, you probably know that it is now possible for sensitive data to remain in an encrypted state even during processing. While FHE enables fundamentally new areas for collaborating securely within and across organizations, it is not a panacea for security. FHE provides data confidentiality by design, but to ensure integrity of the data and enable a secure runtime, additional security layers are required. This lab will show how you can deploy your FHE toolkit image to a Hyper Protect Virtual Server (HPVS) in order to ensure the integrity of the data and enable a secure runtime. Together, HPVS and FHE offer an unrivaled security experience.

## 1.1 High Level Architecture





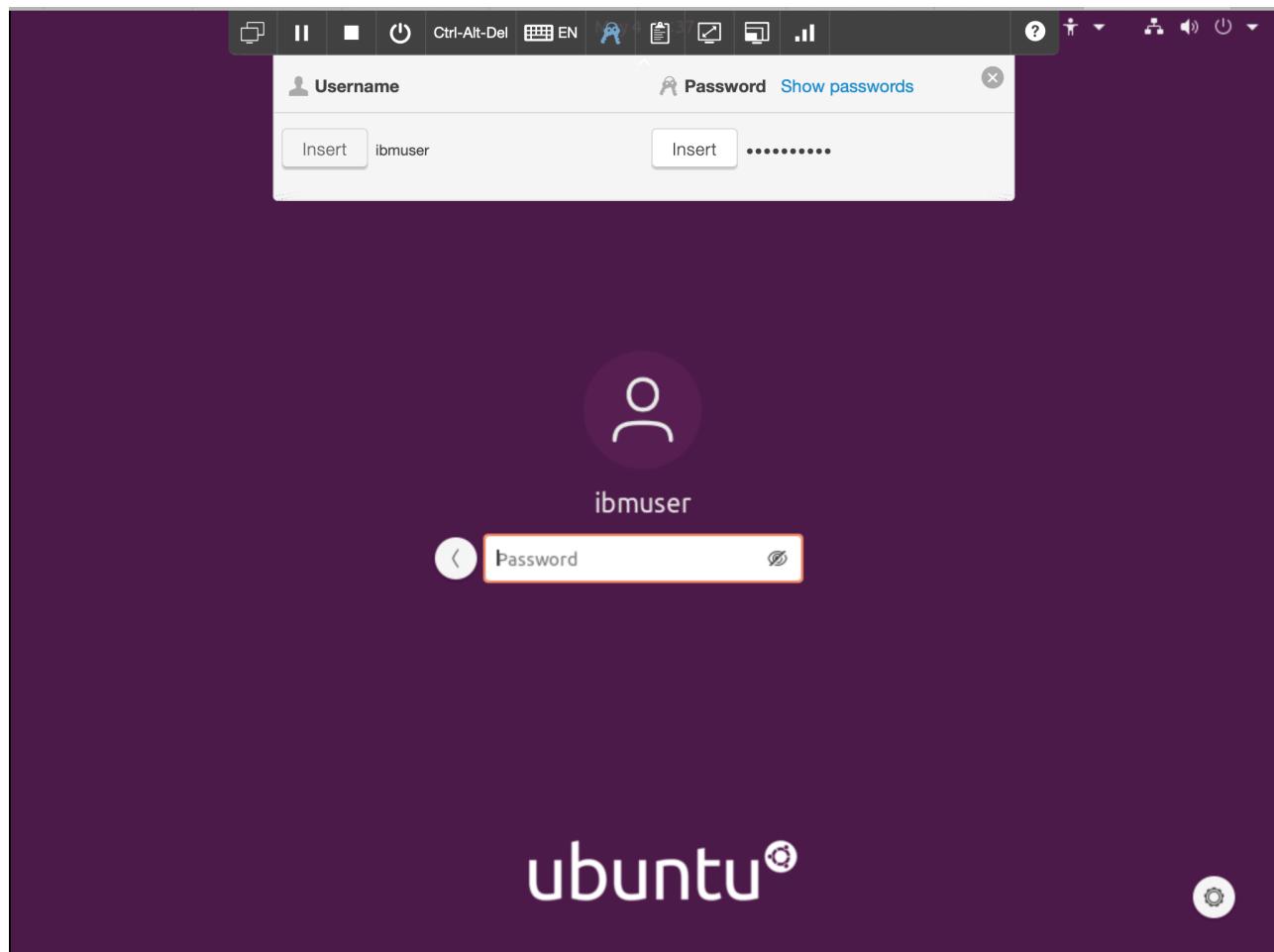
## 2 Getting Started

### Prerequisites

We have prepared a Virtual Machine (VM) running Ubuntu 20.04 that includes all of the software and packages that are needed to run this lab. For a complete list of what is needed to run on your own machine, please refer to the github link below.

Your VM has pre-installed the code repository that we will be working with. All of the code in this lab is open source and readily available for you to run and collaborate on your own machine. For further reference please see <https://github.com/IBM/fhe-toolkit-linux>.

1. When you first open the VM from the Skytap portal, you will see a login screen. Click on the ibmuser to login - it will require a password. On the top VM menu, click on the keys icon, the credentials dropdown will appear. Click Insert under Password, and it will fill in the password. Alternately, if you want to enter it manually, the password is 1bm2021rhjb.



On your VM, cd to the cloned repo already saved onto your VM

```
[fhe-user@centos ~]$ cd /home/ibmuser  
[fhe-user@centos ~]$ cd fhe-toolkit-linux
```

- When you registered for this lab session, you were automatically invited to join the THINK 21 IBM Cloud account. Check your email account that you used to register for the session. You should see an email like the one below. Click on the “Join now!” link to get started.

You are invited to join an account in IBM Cloud [Inbox](#)



IBM Cloud <no-reply@cloud.ibm.com>  
to me ▾

Apr 26, 2021, 4:05 PM (3 days ago)



Hi [fhe.ibm.456@gmail.com](mailto:fhe.ibm.456@gmail.com),

You've been invited by soleilonibmcloud2 soleilonibmcloud2 to IBM Cloud, soleilonibmcloud2 soleilonibmcloud2's Account / SL2245950! Click the link that follows to get started. When you click to join IBM Cloud, you accept the [Terms of Use](#).

[Join now!](#)

Once logged in, use the three bars in the upper left hand corner of the console to access the navigation menus.

Welcome to IBM Cloud!

Thank you,  
IBM Cloud

3. If you can't find that email, go to a browser, navigate to <https://cloud.ibm.com/registration> to create an IBM Cloud account. Make sure to use the email that you registered for the Lab Session to create a new account. If you have already created an account using that email, login using this link: <https://cloud.ibm.com/login>

The screenshot shows the IBM Cloud registration process. At the top, there's a navigation bar with 'IBM Cloud' on the left and 'Catalog', 'Cost estimator', and 'Docs' on the right. Below the navigation bar, there's a small cloud icon and a link to log in if you already have an account. The main area is titled 'Create an account'. It's a three-step process:

- 1. Account information**: Fields for 'Email' (containing 'fhe.123.ibm@gmail.com') and 'Password'. A 'Next' button with a downward arrow is below.
- 2. Verify email**: This step is currently inactive.
- 3. Personal information**: This step is currently inactive.

On the right side of the registration form, there's a large promotional section with a dark blue background and white text:

**Build for free  
on IBM Cloud**

**Develop for free, no credit card required**  
Apps, AI, analytics, and more. Build with 40+ Lite plan services at no cost to you - ever.

**Access the full catalog at your fingertips**  
Upgrade your account and unlock over 350 unique products, plus get a \$200 credit to use with any product you want. [Learn more.](#)

4. In the Top Navigation menu, click on the “Manage” dropdown, Choose “Access (IAM)”. When the new page loads, from the left-hand Navigation panel, select API keys. Click the “Create an IBM Cloud API key” button. Download it and save it somewhere.

Status	Name	Description	Date Created
	API Key	API key created for use by toolchain	2019-06-26 01:09 GMT

An example API key looks like this k-y2lsNxfeKbaidcCG6kQVypLDR\_WjmDPe-2Uuq\_PTYx

5. Open a Terminal and install the IBM Cloud Command Line Interface.

<https://www.ibm.com/cloud/cli>

```
[fhe-user@centos ~]$ curl -sL https://raw.githubusercontent.com/IBM-Cloud/ibm-cloud-developer-tools/master/linux-installer/idt-installer | bash
```

6. Test that it was successfully installed.

```
[fhe-user@centos ~]$ ibmcloud help
```

If it was installed successfully, it will list information and all the commands that are possible to use from the command line.

```
[fhe-user@centos ~]$ ibmcloud help
NAME:
ibmcloud - A command line tool to interact with IBM Cloud
Find more information at: https://ibm.biz/cli-docs.....
```

7. Using the Terminal, login to the ibmcloud, using the API Key that was previously saved in Step 5.

```
[fhe-user@centos ~]$ ibmcloud login -apikey <YOUR API KEY from Step 5>
```

8. Once you have logged in, you will be asked to select a region. Please select the one that best applies to you.

```
[fhe-user@centos ~]$ ibmcloud login -apikey ****
API endpoint: https://cloud.ibm.com
Authenticating...
OK

Targeted Account

Select a region (or press enter to skip):
1. au-syd
2. in-che
3. jp-osa
4. jp-tok
5. kr-seo
6. eu-de
7. eu-gb
8. ca-tor
9. us-south
10. us-east
Enter a number> 9
Targeted region us-south
```

Remember what region you select because you will need the first two letters from the region to build your registry URL in a later step. Example: us-south becomes us.icr.io

9. Set up a namespace. This namespace needs to be unique across all accounts of IBM, so putting your name/business or something unique in the name should suffice. You will need this later when you fill out the config file and it asks for your namespace.

```
[fhe-user@centos ~]$ ibmcloud cr namespace-add fhe-hpvs-demo-your-name
```

10. Update to the latest container plugin for the ibmcloud cli.

```
[fhe-user@centos ~]$ ibmcloud plugin update container-registry
```

11. Install the Hyper Protect Virtual Server plugin (not available for all platforms).

```
[fhe-user@centos ~]$ ibmcloud plugin install hpvs
```

12. Using your Terminal cd into the automation directory of the fhe-toolkit-linux repo.

```
[fhe-user@centos ~]$ cd fhe-toolkit-linux/automation
```

13. Start the interactive wizard by calling the DeployToHPVS.sh script with option -c. It needs a name for the file, this can be any name you like, ex: config-100.conf It also requires which linux platform to build. Choose from ubuntu or fedora.

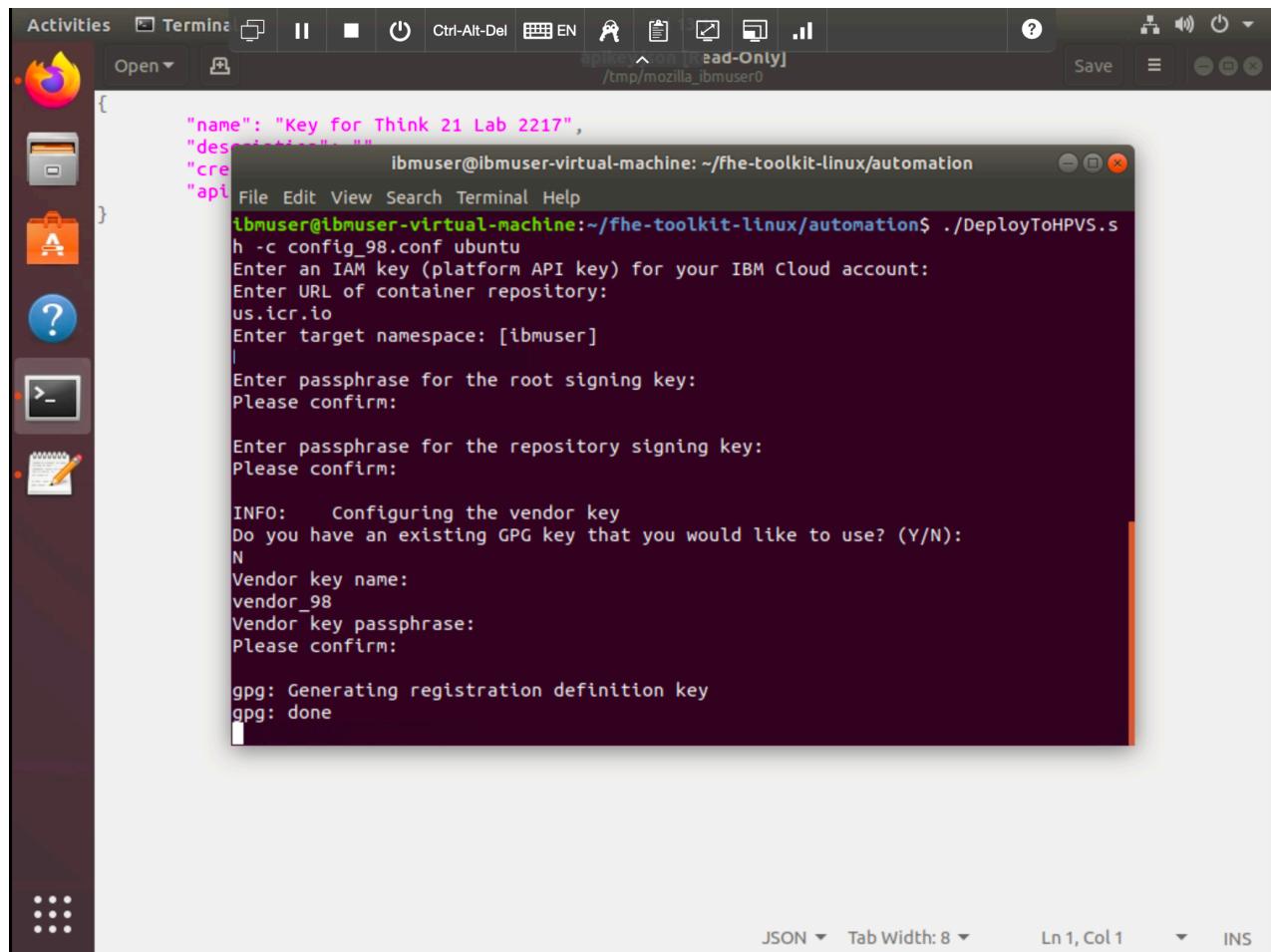
```
[fhe-user@centos ~]$ ./DeployToHPVS.sh -c config-100.conf fedora
```

The interactive wizard requires the following:

- your apikey, from step 5
- the registry url,
  - the two- digit country code from the region you selected in step 9, followed by icr.io ex: us.icr.io
- namespace from step 10.

It will also ask you to create a set of keys that will be used to sign your image.

14. Follow the steps of the interactive wizard to create the configuration file.



The screenshot shows a terminal window titled "ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/automation". The window displays the following command and its output:

```
ibmuser@ibmuser-virtual-machine:~/fhe-toolkit-linux/automation$ ./DeployToHPVS.sh -c config_98.conf ubuntu
Enter an IAM key (platform API key) for your IBM Cloud account:
Enter URL of container repository:
us.icr.io
Enter target namespace: [ibmuser]
|
Enter passphrase for the root signing key:
Please confirm:

Enter passphrase for the repository signing key:
Please confirm:

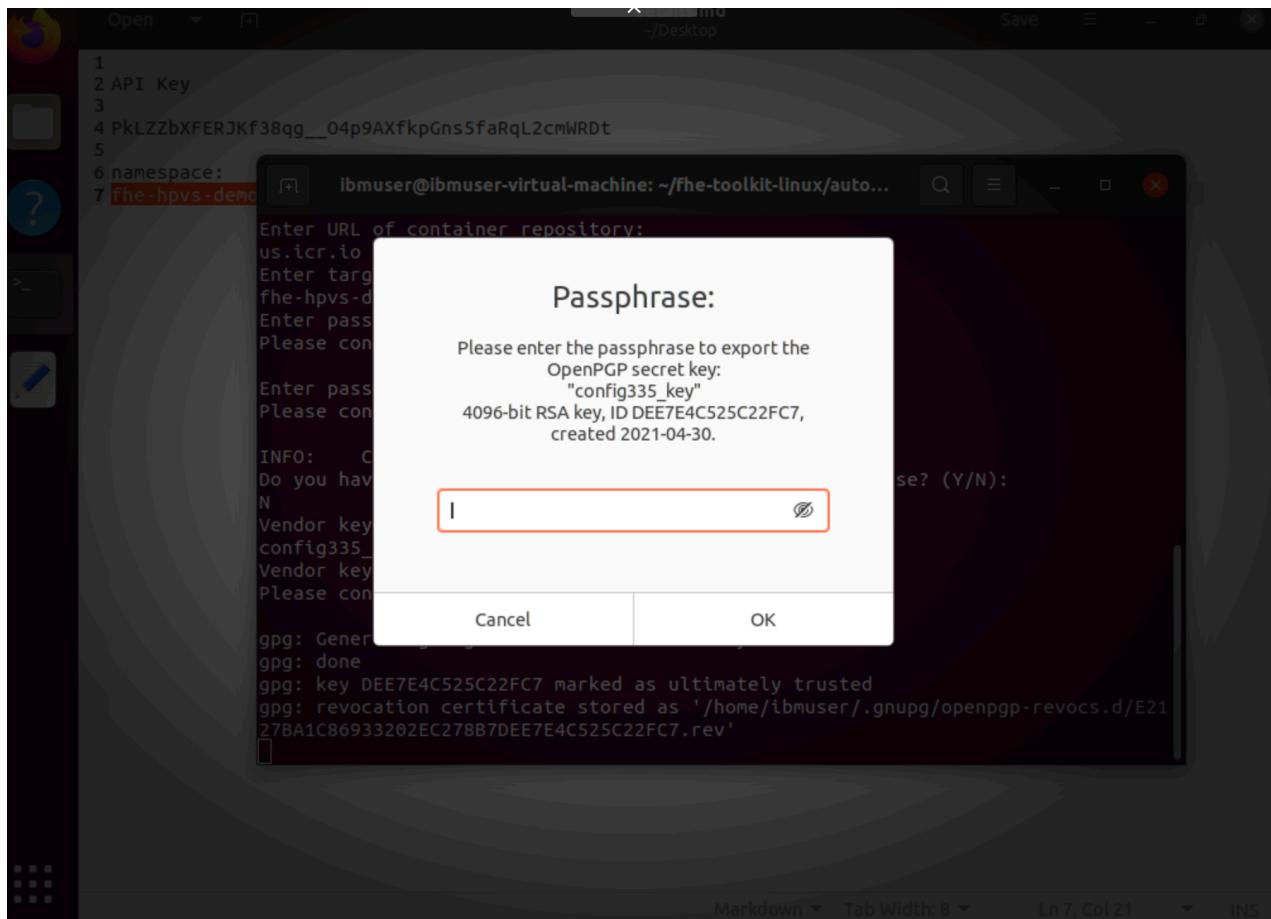
INFO: Configuring the vendor key
Do you have an existing GPG key that you would like to use? (Y/N):
N
Vendor key name:
vendor_98
Vendor key passphrase:
Please confirm:

gpg: Generating registration definition key
gpg: done
```

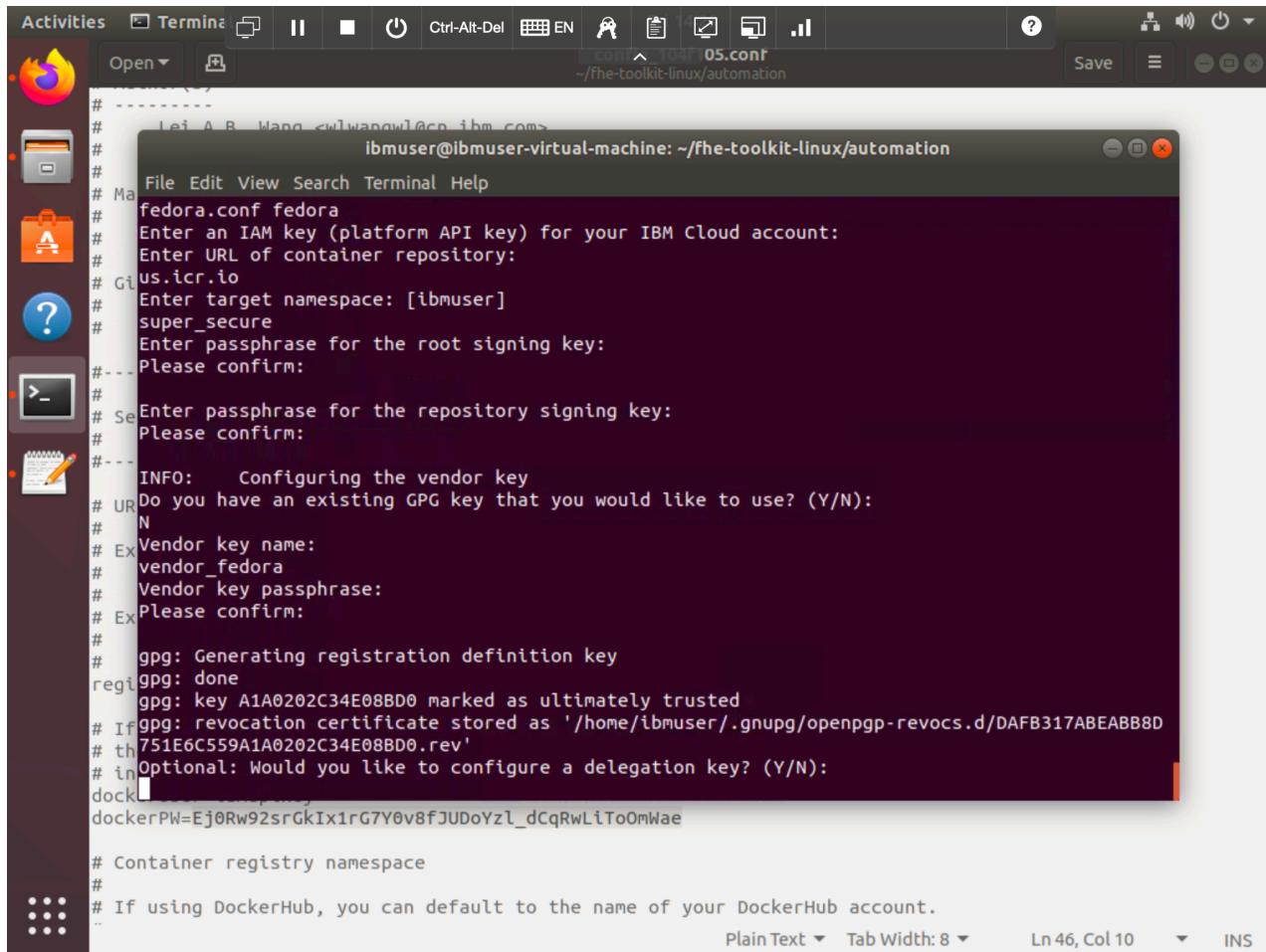
The terminal window has a dark background and light-colored text. It includes standard Linux terminal icons at the top and a vertical toolbar on the left with icons for file operations like Open, Save, and Close. At the bottom, there are status indicators for JSON, Tab Width, Line, Column, and Insert mode.

During the script it will generate a set of keys using the gpg suite of tools. Because these keys can be quite large, it will take some time to build depending on the CPU power of your particular virtual machine.

15. Once the script has generated the key it will ask you to input your password for the key in order to export it for signing the image in the registry. Enter your password that you made during the script when it asked for a root key password.

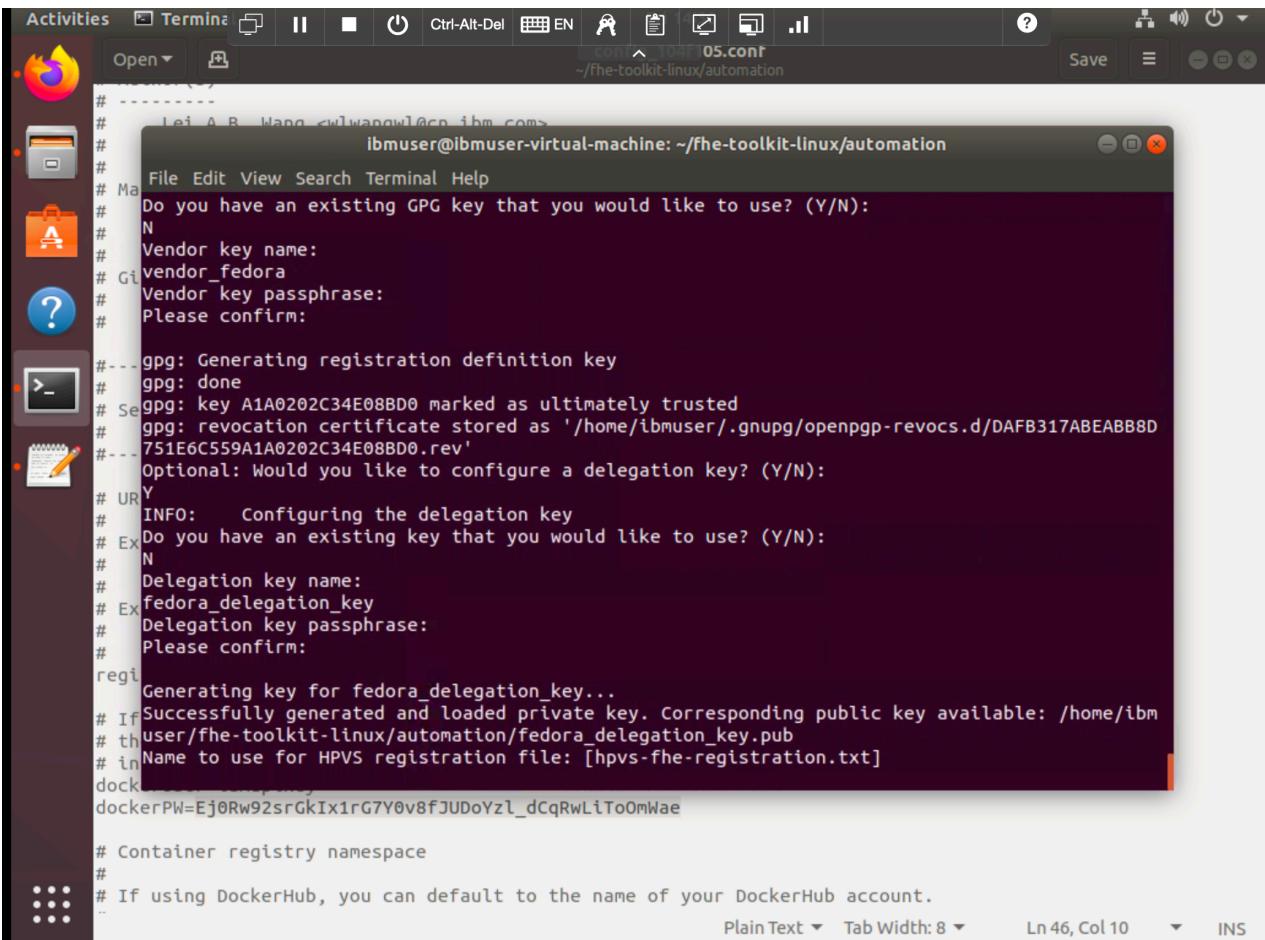


16. It will then ask you if you want to make a delegation key. Indicate yes by typing a “Y”, then give it a name and a password.



```
# -----  
# Lei A.B. Wang <wlwangwl@cn.ibm.com>  
# ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/automation  
# File Edit View Search Terminal Help  
fedora.conf fedora  
# Enter an IAM key (platform API key) for your IBM Cloud account:  
# Enter URL of container repository:  
# Gi.us.icr.io  
# Enter target namespace: [ibmuser]  
# super_secure  
# Enter passphrase for the root signing key:  
#---Please confirm:  
# Enter passphrase for the repository signing key:  
# Please confirm:  
#---  
# INFO: Configuring the vendor key  
# Do you have an existing GPG key that you would like to use? (Y/N):  
# N  
# Vendor key name:  
# vendor_fedora  
# Vendor key passphrase:  
# Please confirm:  
# gpg: Generating registration definition key  
reggpg: done  
gpg: key A1A0202C34E08BD0 marked as ultimately trusted  
# If gpg: revocation certificate stored as '/home/ibmuser/.gnupg/openpgp-revocs.d/DAFB317ABEABB8D  
# th751E6C559A1A0202C34E08BD0.rev'  
# inOptional: Would you like to configure a delegation key? (Y/N):  
docke  
dockerPW=Ej0Rw92srGkIx1rG7Y0v8fJUDoYzl_dCqRwLiTo0mWae  
# Container registry namespace  
#  
# If using DockerHub, you can default to the name of your DockerHub account.  
..
```

17. Next, it will ask for a name to use for HPVS registration file. Hit Enter here and leave it blank. It will default to the file that is pre-made by the script.

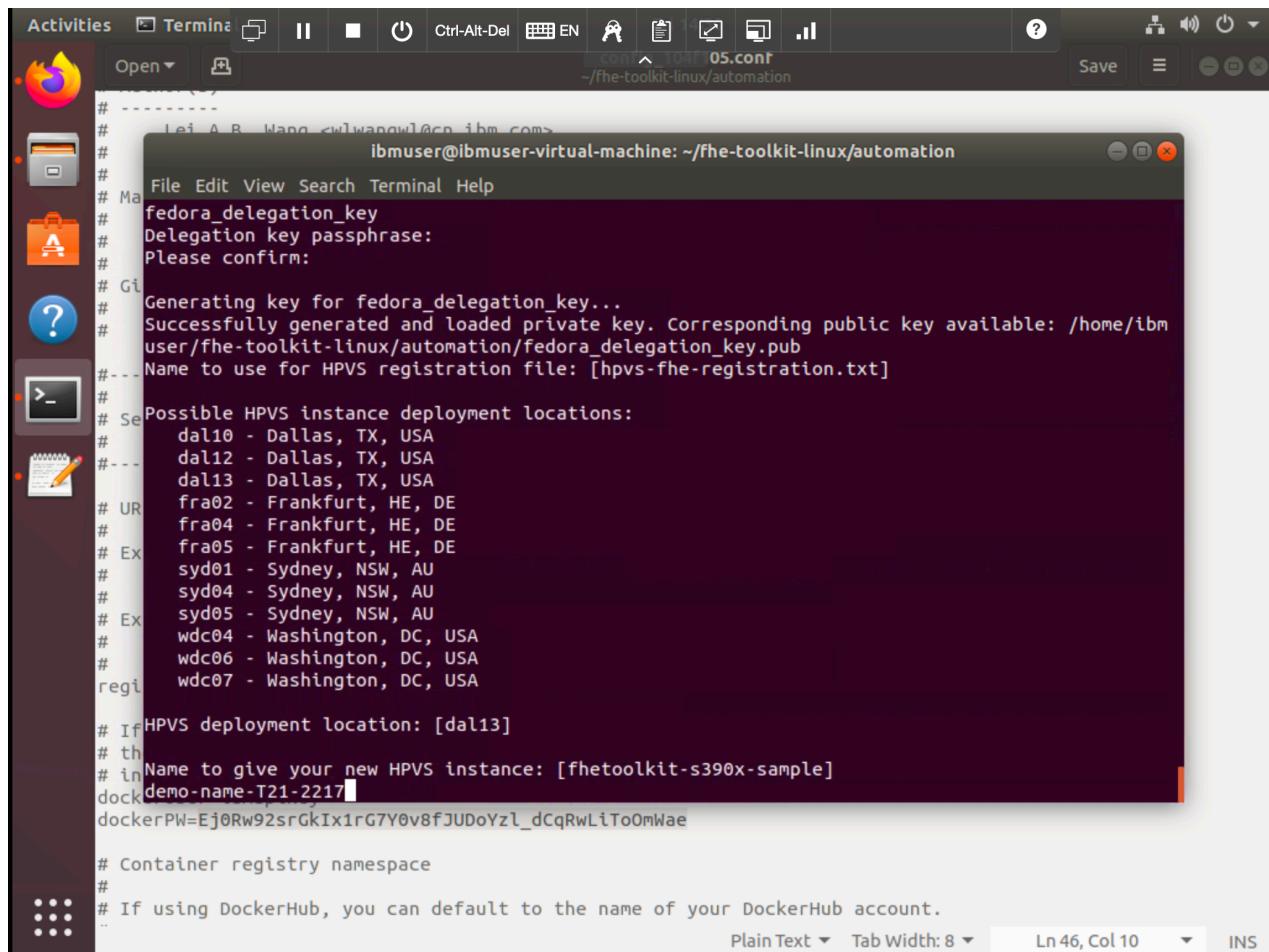


```
# -----  
# Lei A.B. Wang <wlwangowl@cn.ibm.com>  
# ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/automation  
# Ma  
# File Edit View Search Terminal Help  
# Do you have an existing GPG key that you would like to use? (Y/N):  
# N  
# Vendor key name:  
# vendor_fedora  
# Vendor key passphrase:  
# Please confirm:  
#---gpg: Generating registration definition key  
# gpg: done  
# Seagpg: key A1A0202C34E08BD0 marked as ultimately trusted  
# gpg: revocation certificate stored as '/home/ibmuser/.gnupg/openpgp-revocs.d/DAFB317ABEABB8D  
# 751f6C559A1A0202C34E08BD0.rev'  
# Optional: Would you like to configure a delegation key? (Y/N):  
# URY  
# INFO: Configuring the delegation key  
# Do you have an existing key that you would like to use? (Y/N):  
# N  
# Delegation key name:  
# fedora_delegation_key  
# Delegation key passphrase:  
# Please confirm:  
regi  
Generating key for fedora_delegation_key...  
# Successfully generated and loaded private key. Corresponding public key available: /home/ibm  
# user/fhe-toolkit-linux/automation/fedora_delegation_key.pub  
# inName to use for HPVS registration file: [hpvs-fhe-registration.txt]  
dock  
dockerPW=Ej0Rw92srGkIx1rG7Y0v8fJUDoYzl_dCqRwLiToOmWae  
# Container registry namespace  
#  
# If using DockerHub, you can default to the name of your DockerHub account.  
..
```

Plain Text ▾ Tab Width: 8 ▾ Ln 46, Col 10 ▾ INS

18. The next step in the script asks for the region where you want it to be provisioned. Choose the location that is closest to your region of the world. The default is dal13 for Dallas, Texas, USA. Please choose from the list that it presents to you (see image below) by typing in its initials and pressing enter.

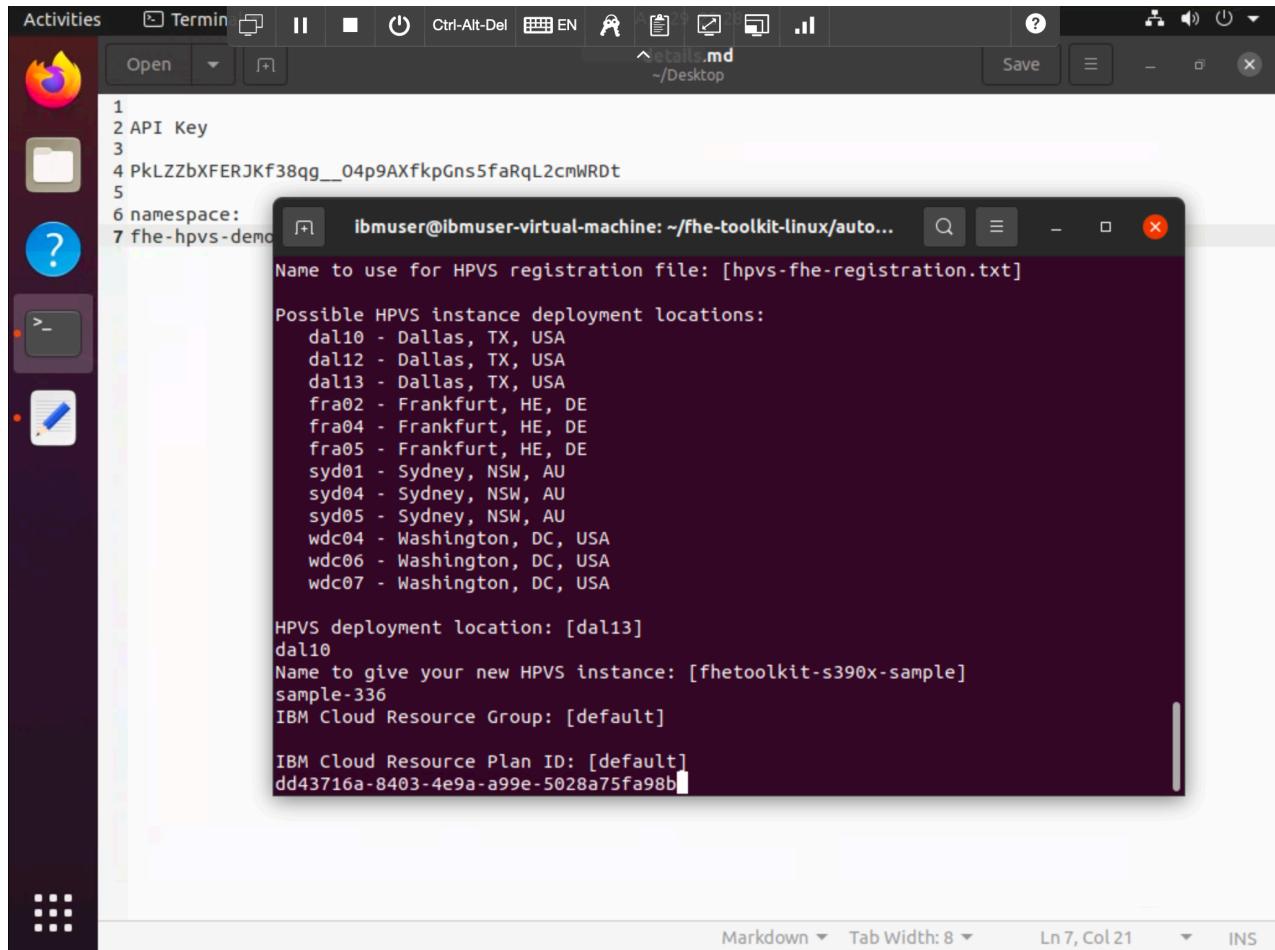
Then it will need a name for the image once it's deployed to Hyper Protect. You can give it a name or hit enter and it will default to "fhetoolkit-s390x-sample." For this lab, because we are sharing the same account it will be a good idea to give it a name that you will easily recognize when you have to pick it out of a list.



```
# -----  
#   Lei A.B. Wang <culwangwl@cn.ibm.com>  
#   ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/automation  
#  
#   File Edit View Search Terminal Help  
#   fedora_delegation_key  
#   Delegation key passphrase:  
#   Please confirm:  
#  
#   Generating key for fedora_delegation_key...  
#   Successfully generated and loaded private key. Corresponding public key available: /home/ibm  
#   user/fhe-toolkit-linux/automation/fedora_delegation_key.pub  
#  
#   Name to use for HPVS registration file: [hpvs-fhe-registration.txt]  
#  
#  
#   Possible HPVS instance deployment locations:  
#       dal10 - Dallas, TX, USA  
#       dal12 - Dallas, TX, USA  
#       dal13 - Dallas, TX, USA  
#       fra02 - Frankfurt, HE, DE  
#       fra04 - Frankfurt, HE, DE  
#       fra05 - Frankfurt, HE, DE  
#       syd01 - Sydney, NSW, AU  
#       syd04 - Sydney, NSW, AU  
#       syd05 - Sydney, NSW, AU  
#       wdc04 - Washington, DC, USA  
#       wdc06 - Washington, DC, USA  
#       wdc07 - Washington, DC, USA  
#  
#   If HPVS deployment location: [dal13]  
#  
#   Name to give your new HPVS instance: [fhetoolkit-s390x-sample]  
dockdemo-name-T21-2217  
dockerPW=Ej0Rw92srGkIx1rG7Y0v8fJUDoYzl_dCqRwLiTo0mWae  
# Container registry namespace  
#  
# If using DockerHub, you can default to the name of your DockerHub account.  
#
```

The last few entry inputs you can hit enter and bypass them (they will use the default parameters). For your virtual machine, the resource plan ID has already been added, but if you run into an issue when it deploys that states you are out of free instances for your plan, enter this ID:

```
dd43716a-8403-4e9a-a99e-5028a75fa98b
```



A screenshot of a Linux desktop environment showing a terminal window. The terminal window title is "ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/auto...". The terminal content shows the following steps for FHE registration:

```
1
2 API Key
3
4 PkLZZbXFERJKf38qg__04p9AXfkpGns5faRqL2cmWRDt
5
6 namespace:
7 fhe-hpvs-demo
```

The terminal then prompts for the registration file name:

```
Name to use for HPVS registration file: [hpvs-fhe-registration.txt]
```

It lists possible HPVS instance deployment locations:

```
Possible HPVS instance deployment locations:
dal10 - Dallas, TX, USA
dal12 - Dallas, TX, USA
dal13 - Dallas, TX, USA
fra02 - Frankfurt, HE, DE
fra04 - Frankfurt, HE, DE
fra05 - Frankfurt, HE, DE
syd01 - Sydney, NSW, AU
syd04 - Sydney, NSW, AU
syd05 - Sydney, NSW, AU
wdc04 - Washington, DC, USA
wdc06 - Washington, DC, USA
wdc07 - Washington, DC, USA
```

It sets the HPVS deployment location to dal13:

```
HPVS deployment location: [dal13]
dal10
```

It prompts for the new HPVS instance name:

```
Name to give your new HPVS instance: [fhetoolkit-s390x-sample]
sample-336
```

It sets the IBM Cloud Resource Group to default:

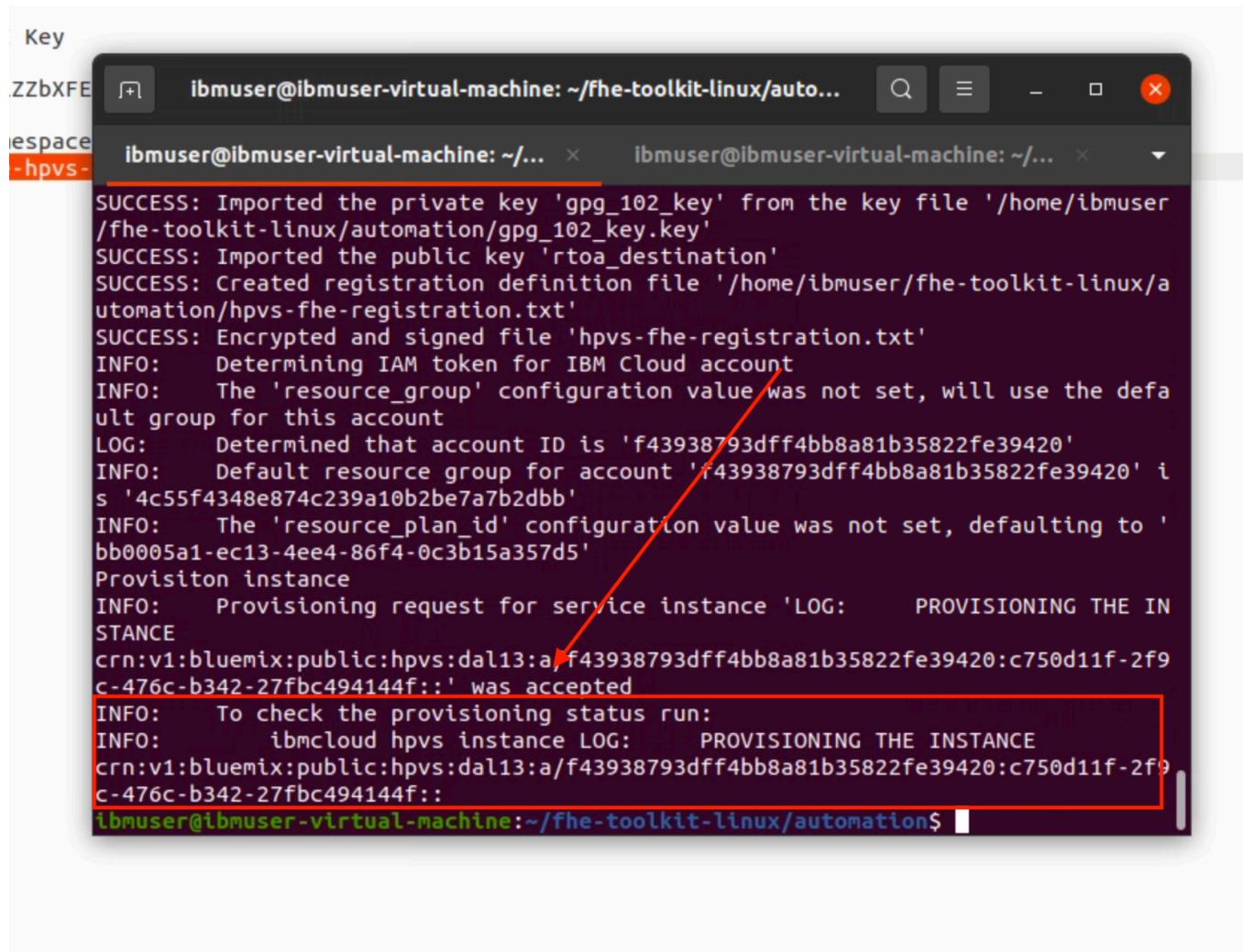
```
IBM Cloud Resource Group: [default]
```

Finally, it sets the IBM Cloud Resource Plan ID to dd43716a-8403-4e9a-a99e-5028a75fa98b:

```
IBM Cloud Resource Plan ID: [default]
dd43716a-8403-4e9a-a99e-5028a75fa98b
```

At the bottom of the terminal window, status indicators show "Markdown", "Tab Width: 8", "Ln 7, Col 21", and "INS".

19. The script will now sign and deploy the image to the Hyper Protect Virtual Server. When it is done, it will show the ID of the new image. To see more details about the deployed image, go to your Dashboard section of <https://cloud.ibm.com>.



```
Key
ZZbXFE ibmuser@ibmuser-virtual-machine: ~/fhe-toolkit-linux/automation...
espace ibmuser@ibmuser-virtual-machine: ~/... x ibmuser@ibmuser-virtual-machine: ~/...
-hpvs- SUCCESS: Imported the private key 'gpg_102_key' from the key file '/home/ibmuser/fhe-toolkit-linux/automation/gpg_102_key.key'
SUCCESS: Imported the public key 'rto_a_destination'
SUCCESS: Created registration definition file '/home/ibmuser/fhe-toolkit-linux/automation/hpvs-fhe-registration.txt'
SUCCESS: Encrypted and signed file 'hpvs-fhe-registration.txt'
INFO: Determining IAM token for IBM Cloud account
INFO: The 'resource_group' configuration value was not set, will use the default group for this account
LOG: Determined that account ID is 'f43938793dff4bb8a81b35822fe39420'
INFO: Default resource group for account 'f43938793dff4bb8a81b35822fe39420' is '4c55f4348e874c239a10b2be7a7b2dbb'
INFO: The 'resource_plan_id' configuration value was not set, defaulting to 'bb0005a1-ec13-4ee4-86f4-0c3b15a357d5'
Provisioning instance
INFO: Provisioning request for service instance 'LOG: PROVISIONING THE INSTANCE
crn:v1:bluemix:public:hpvs:dal13:a/f43938793dff4bb8a81b35822fe39420:c750d11f-2f9c-476c-b342-27fbc494144f::' was accepted
INFO: To check the provisioning status run:
INFO: ibmcloud hpvs instance LOG: PROVISIONING THE INSTANCE
crn:v1:bluemix:public:hpvs:dal13:a/f43938793dff4bb8a81b35822fe39420:c750d11f-2f9c-476c-b342-27fbc494144f::
ibmuser@ibmuser-virtual-machine:~/fhe-toolkit-linux/automation$
```

20. Click on Services to see the deployed Virtual Server images from the Dashboard section of cloud.ibm.com.

The screenshot shows the IBM Cloud Resource list interface. The left sidebar contains navigation icons for various services: Devices, VPC infrastructure, Clusters, Satellite, Cloud Foundry apps, Cloud Foundry services, Services, Storage, Network, Functions namespaces, Apps, and Developer tools. The 'Services' section is expanded, showing three entries: Internet Services-a1, Internet Services-n8, and fhetoolkit-s390x-ubuntu-102. The main table lists these services with columns for Name, Group, Location, Status, and Tags. All three services are listed as Active.

Name	Group	Location	Status	Tags
Internet Services-a1	default	Global	Active	-
Internet Services-n8	default	Global	Active	-
fhetoolkit-s390x-ubuntu-102	default	Dallas 13	Active	-

21. Click on the image listing, then click on “View Full Details” to find the public IP address.

The screenshot shows the IBM Cloud Resource list interface. On the left, there's a sidebar with various icons for different service categories like Devices, VPC infrastructure, Clusters, Satellite, Cloud Foundry apps, Cloud Foundry services, Services, Storage, Network, Functions namespaces, Apps, and Developer tools. The main area displays a table with columns: Name, Group, Location, and Status. There are filters at the top of the table. The table lists three items:

Name	Group	Location	Status
Internet Services-a1	default	Global	Active
Internet Services-n8	default	Global	Active
fhetoolkit-s390x-ubuntu-102	default	Dallas 13	Active

To the right of the table, detailed information for the selected service ('fhetoolkit-s390x-ubuntu-102') is shown:

- Active [View cloud status](#)
- Product: Hyper Protect Virtual Server
- Created: 2021-04-09
- Created by: [User]
- Plan: Free
- CRN: crn:v1:bluemix:public:hyps... [Copy](#)
- GUID: f163792d-d96f-4d7f-b93... [Copy](#)

A large red arrow points from the service name 'fhetoolkit-s390x-ubuntu-102' in the table towards the 'View full details' button, which is highlighted with a blue border.

22. Copy the public IP address and save it.

IBM Cloud

Resource list / fhtoolkit-s390x-ubuntu-102 Active Add tags Details Actions...

Manage

Getting started

Virtual server running smoothly

Your virtual server

Processors	RAM	Boot disk	Data disk
1 vCPUs	2 GiB	25 GiB	25 GiB

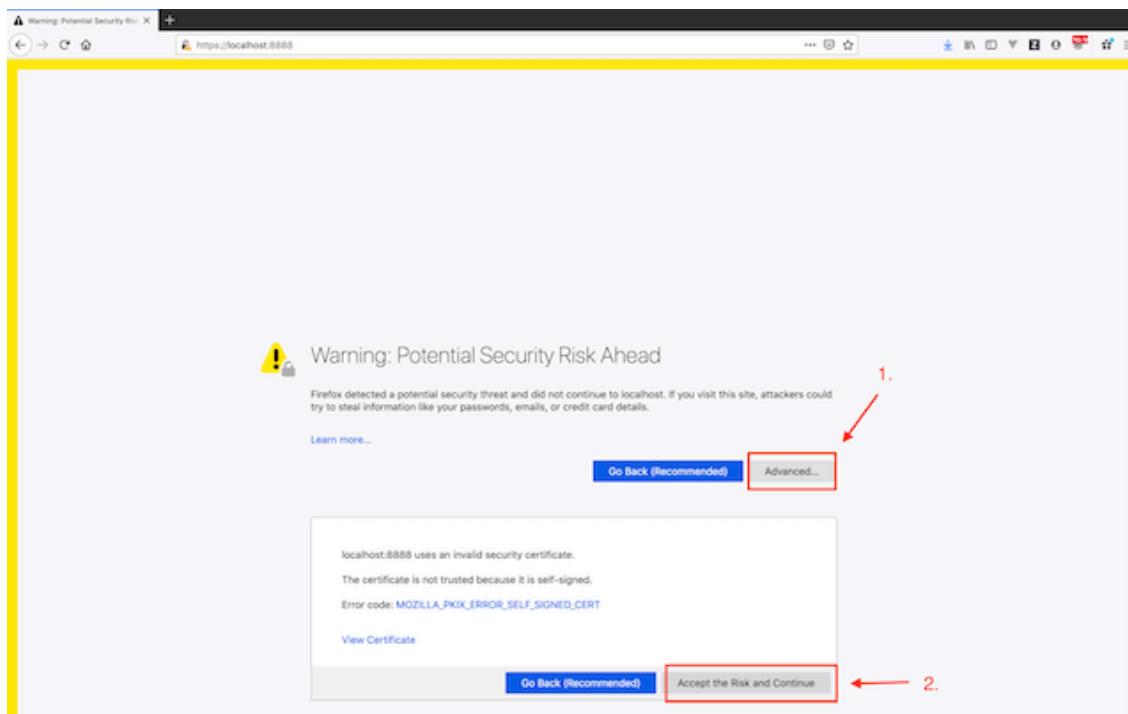
Plan Free Created 4/9/2021 Updated -

Connect

Public IP address 208.43.37.195

Internal IP address 172.18.151.155

23. Open a web browser and browse to your IP address adding the port 8443, it will look like: <https://xxx.xx.xx.xx:8443/>. This will connect you to the IDE running in the FHE toolkit Docker container.

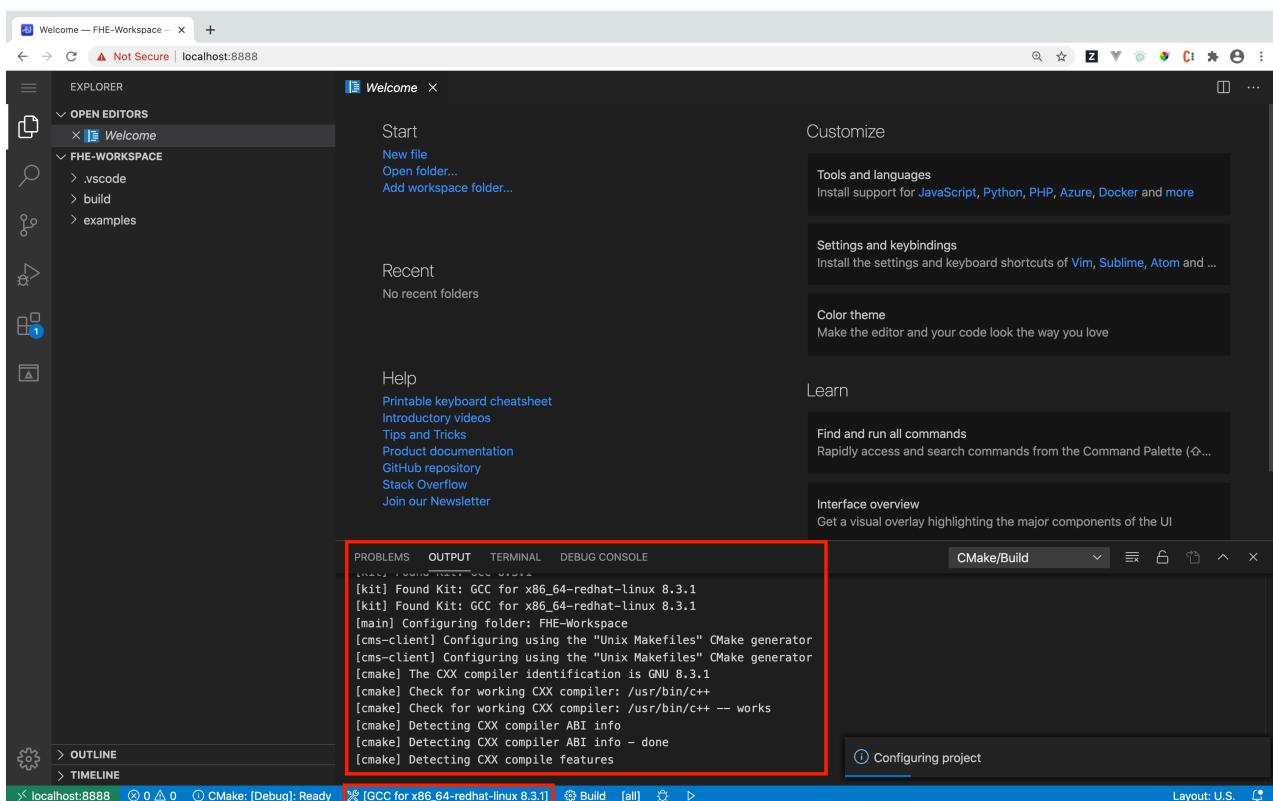
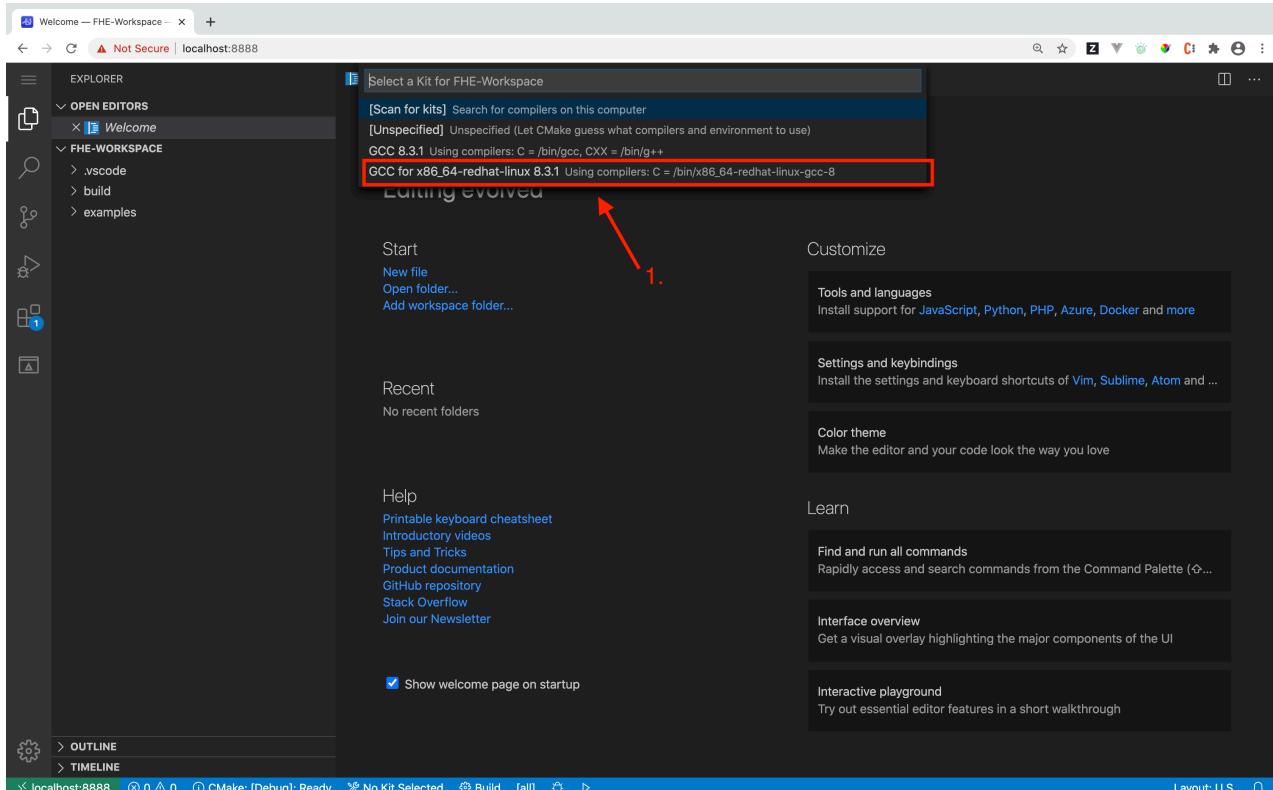


Note that this connection is secured over https using a self-signed certificate. You'll therefore need to tell your browser to trust it each time you connect to a new instance of the toolkit. In Chrome, you can do this by clicking anywhere on the warning test and typing "this is unsafe". If you're using Safari, you'll need to click the "visit this website" link and enter your username and password. For Firefox, click "Advanced", then click "Accept the Risk and Continue".

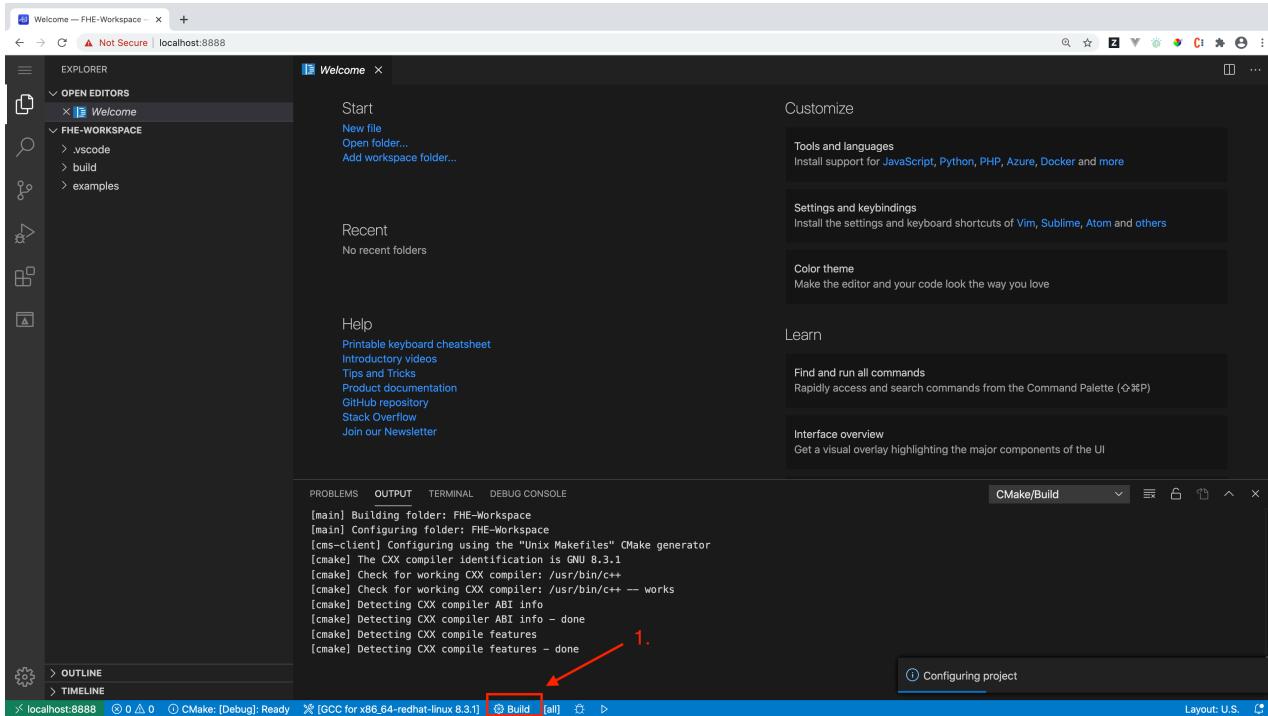
24. Once the toolkit is loaded, you should automatically be prompted to select a kit for the FHE-Workspace to use. Select one of the kits from the dropdown. Configuration of the workspace will begin which you will be able to see in the Output Window. You'll also notice the kit you selected is now shown in the CMake Tools status bar at the bottom of the window.

If you are not automatically prompted to select a kit after a few seconds of loading the toolkit, try refreshing your browser. If you're still not prompted, check the CMake Tools status bar at

the bottom of the window to see if a kit has already been selected. You'll need to select a kit each time you start a new instance of the Toolkit.



25. Click “Build” in the CMake Tools status bar to build the selected target.



26. When the build has finished, click “Launch” in CMake Tools status bar to launch the selected target in the terminal window.

Each demonstration application is in a self-contained directory in the examples folder in the IDE. Each demo application directory contains a README.md that explains how to run the demo and what you should expect for results. For instance, the BGV World Country Database Lookup Example Documentation contains the information to run a complete example of a privacy preserving search against an encrypted database. The database is a key value store prepopulated with the English names of countries and their capital cities from the world. Selecting the country will perform a search of the matching capital.

