



# Testing NVMe<sup>®</sup> Today and Tomorrow

Sponsored by NVM Express organization, the owner of NVMe specifications

# Speaker



Carter Snay

Technical Manager

UNH-IOL



# Agenda

The UNH-IOL and the Beginning of IOL and ICC NVMe<sup>®</sup> Testing

Test Tool Information

Testing NVMe Technology

The Refactoring Effort

NVMe 2.0 Specifications and Beyond

Q&A

# What the UNH-IOL Does



Tests a wide variety of technologies, student driven, staff managed



Neutral 3rd-party testing facility



Host Plugfests and Testing Events



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# Origin of NVMe<sup>®</sup> Specification and Importance of Testing

- Started with PCIe<sup>®</sup> as only transport
  - Admin and NVM I/O Command Sets
  - Testing for the last decade
- Conformance and Interoperability Testing
  - Why?
    - Making sure the product “just works!”



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# NVMe Technology Is Everywhere:

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Solid State Disks



Disaggregated Storage  
Architectures



Cell Phones



Servers



Mobile Computing



Storage Arrays



Data Centers

# Test Plans Based on the Specifications

- Test published by the UNH-IOL, written in conjunction with the NVMe® Interop and Compliance Work Group
- Originally, 2-3 test plans were required for listing on Integrator's List
  - UNH-IOL NVMe Conformance (NVMe-oF Conformance added later)
  - UNH-IOL NVMe Interoperability
  - UNH-IOL NVMe-MI™ Conformance (if supported)



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# Test Plan Development Process

1

Updates to test plans happen twice a year in order to keep pace with updates to the NVMe<sup>®</sup> specifications being developed at [nvmexpress.org](http://nvmexpress.org)

2

All test plan updates are created by NVMe Interop and Compliance Committee.



3

All updates are approved and voted on by the NVMe Technical Work Group and the NVMe Board of Directors.



4

All new tests added are made FYI, since in many cases there are no existing product in the market. This gives time for the test plan, DUT, and test scripts to be vetted.



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# NVMe Test Plans

The test plans on this page may be downloaded and used for internal purposes only. The test plans may not be commercialized in any way without express permission of the UNH-IOL.

The NVMe testing service currently offers the following test plans. These documents are constantly being updated to improve readability and to reflect the current specifications. Please contact us if you would like more information or have questions about the NVMe testing service.

When testing based on the following test plans is performed, all reports generated will be digitally signed using an Adobe digital certificate. Upon reception of the report, the recipient can verify its authenticity using our [document validation instructions](#).

## IOL

### Conformance

▶ UNH-IOL NVMe Conformance v16.0 (PCIe based NVMe SSDs and NVMe-oF NVM Subsystems)

▶ UNH-IOL NVM Command Set Conformance v17.0

▶ UNH-IOL NVMe-MI Conformance v17.0

▶ UNH-IOL NVMe ZNS Command Set Conformance v17.0

▶ UNH-IOL NVMe PCIe Transport Conformance v17.0

▶ UNH-IOL NVMe Conformance v15.0 (PCIe based NVMe SSDs and NVMe-oF NVM Subsystems)

▶ UNH-IOL NVMe-ZNS Conformance v16.0

▶ UNH-IOL NVMe-ZNS Conformance v15.0

▶ UNH-IOL NVMe-MI Conformance v16.0

▶ UNH-IOL NVMe-MI Conformance v15.0

### Interoperability

▶ UNH-IOL NVMe Interoperability v16.0 (PCIe based NVMe Hosts and SSDs)

▶ UNH-IOL NVMe PCIe Interoperability v17.0

▶ UNH-IOL NVMe Interoperability v15.0 (PCIe based NVMe Hosts and SSDs)



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# The NVMe® Integrator's List

## NVMe™ Integrator's List

The NVMe Integrator's List (IL) contains useful information about NVMe Products that UNH-IOL has performed interoperability and conformance testing during an NVMe plugfest or through test reservations at our lab. Successful completion of such conformance tests when combined with satisfactory operation in UNH-IOL's interoperability tests provides a reasonable level of confidence that the Product Under Test will function properly in many NVMe environments. UNH-IOL is happy to be collaborating with the NVMe Organization on the creation and maintenance of the NVMe Integrator List. More information on NVMe Products can be found at [nvmexpress.org/products](http://nvmexpress.org/products).



## NVMe™ Integrator's List v1.0 | NVMe-oF™ Integrator's List

- NVMe Integrator's List Policy v1.0

### NVMe Devices

Product Name + Firmware Version	Product Type	PCIe Gen	NVMe Base Spec Version	Form Factor	I/O Command Sets Supported	Interop Program Revision	Date Listed	Further Info
SK Hynix PC301 Firmware Version: S1020A20	NVMe SSD	Gen4	1.4	N/A	M.2	NVM	v1.0	May 10, 2022 <a href="http://www.skhynix.com">www.skhynix.com</a>
SK Hynix BC801 Firmware Version: C000H01	NVMe SSD	Gen4	1.4	N/A	M.2	NVM	v1.0	May 10, 2022 <a href="http://www.skhynix.com">www.skhynix.com</a>
Longsys XP2100 Firmware Version: V1.1.2	NVMe SSD	Gen4x4	1.4	N/A	M.2	NVM	v1.0	April 22, 2022 <a href="http://www.longsys.com">www.longsys.com</a>
Longsys XP2000 Firmware Version: V1.2.2	NVMe SSD	Gen3x4	1.4	N/A	M.2	NVM	v1.0	April 22, 2022 <a href="http://www.longsys.com">www.longsys.com</a>
Samsung PM174a Firmware Version: DPP10B54	NVMe SSD	Gen5	1.4	1.1	U.2/E.3.S	NVM	v1.0	April 20, 2022 <a href="http://www.samsung.com/sec">www.samsung.com/sec</a>
Samsung PM9E1 Firmware Version: HVC7002U	NVMe SSD	Gen4	1.4	N/A	M.2	NVM	v1.0	April 20, 2022 <a href="http://www.samsung.com/sec">www.samsung.com/sec</a>
Phison PS5015-E1ST Firmware Version: EHFMB0.0	NVMe SSD	Gen4	1.4	NA	M.2 2280	NVM	v1.0	April 11, 2022 <a href="https://www.phison.com/zh-tw/">https://www.phison.com/zh-tw/</a>
Phison PS5015-E2T Firmware Version: ELMFB0.2	NVMe SSD	Gen4x4	1.4	NA	M.2 2280	NVM	v1.0	April 11, 2022 <a href="https://www.phison.com/zh-tw/">https://www.phison.com/zh-tw/</a>
Shenzhen Unionmemory Information System Ltd. AM640 Firmware Version: 1.0C0640	NVMe SSD	Gen4	1.4	N/A	M.2	NVM	v1.0	March 29th, 2022 <a href="http://www.unionmem.com/">http://www.unionmem.com/</a>
Shenzhen Unionmemory Information System Ltd. AM650 Firmware Version: 1.0C0650	NVMe SSD	Gen4	1.4	N/A	M.2	NVM	v1.0	March 29th, 2022 <a href="http://www.unionmem.com/">http://www.unionmem.com/</a>
Shenzhen Unionmemory Information System Ltd. AM644 Firmware Version: 1.0C0644	NVMe SSD	PCIe Gen4	1.4	N/A	M.2	NVM	v1.0	March 29th, 2022 <a href="http://www.unionmem.com/">http://www.unionmem.com/</a>
Seagate® Nytro® S350 Firmware Version: SE05SA300	NVMe SSD	Gen 4	1.4	1.1	U.2 and U.3	NVM	1.0	March 14th, 2022 <a href="https://www.seagate.com/us/en/">https://www.seagate.com/us/en/</a>
Longsys FORESEE F709 NVMe SSD	NVMe SSD	Gen 3x4	1.3	NA	M.2	NVM	1.0	March 8th, 2022 <a href="http://www.longsys.com">www.longsys.com</a>
Longsys FORESEE XP2000	NVMe	Gen 1.4	NA	M.2	NVM	1.0	March	<a href="http://www.longsys.com">www.longsys.com</a>

Longsys XP1000(P100)	NVMe SSD	Gen 3x4	1.4	NA	M.2	NVM	1.0	March 8th, 2022 <a href="http://www.longsys.com">www.longsys.com</a>	
YMTC P420 Firmware Version: Y401128	NVMe SSD	Gen4	1.4	NA	U.2	NVM	v1.0	March 3rd, 2022 TBA	
DEIRA D6000 Series NVMe SSD (D6436/D6437/D6456/D6457) Firmware Version: D6K000Q2	NVMe SSD	Gen3	1.4	NA	U.2	NVM	v1.0	February 28, 2022 <a href="http://www.derastorage.com">www.derastorage.com</a>	
Micron 2400 NVMe SSD Firmware Version: Z3A4000	NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	February 22nd, 2022 <a href="http://www.micron.com">www.micron.com</a>	
ADATA Technology M2P1248 NVMe SSD Firmware Version: 02112024	NVMe SSD	Gen3	1.4	NA	M.2	NVM	v1.0	February 9th, 2022 <a href="http://industrial.adata.com">industrial.adata.com</a>	
Phison PS5010 E30 NVMe SSD Firmware Version: EXM30E7	NVMe SSD	Gen4	1.4	1.1	U.2 and U.3	NVM	v1.0	January 31, 2022 <a href="https://www.phison.com/zh-tw/">https://www.phison.com/zh-tw/</a>	
Inspur NS8500/NS8600 G2 NVMe SSD Firmware Version: NS800204	NVMe SSD	Gen4	1.4	NA	U.2	NVM	v1.0	January 27, 2022 <a href="https://inspur.com/">https://inspur.com/</a>	
Dapostar Corporation J5100 NVMe Firmware Version: FF0202A	NVMe SSD	Gen4	1.4	NA	U.2	NVM	v1.0	January 21, 2022 <a href="http://dapostar.com">dapostar.com</a>	
Dapostar Corporation K2900 NVMe Firmware Version: FF0202A	NVMe SSD	Gen4	1.4	NA	U.2	NVM	v1.0	January 21, 2022 <a href="http://dapostar.com">dapostar.com</a>	
Dapostar Corporation R5100 NVMe Firmware Version: FF0202A	NVMe SSD	Gen4	1.4	NA	U.2	NVM	v1.0	January 21, 2022 <a href="http://dapostar.com">dapostar.com</a>	
Dapostar Corporation R5100 NVMe Firmware Version: FF0202A	NVMe SSD	Gen4	1.4	NA	AIC	NVM	v1.0	January 21, 2022 <a href="http://dapostar.com">dapostar.com</a>	
Dapostar Corporation J5110 NVMe Firmware Version: FF0202A	NVMe SSD	Gen4	1.4	NA	AIC	NVM	v1.0	January 21, 2022 <a href="http://dapostar.com">dapostar.com</a>	
Western Digital Ultrastar DC ZN40 NVMe Firmware Version: R1Z210009	NVMe SSD	Gen4	1.4	M.1	U.2	NVM	v1.0	January 18, 2022 <a href="https://www.westerndigital.com/">https://www.westerndigital.com/</a>	
Intel® Optane™ SSD DC P5810 Series Firmware Version: LAD10300	NVMe SSD	Gen4	1.4	M.1	U.2	NVM	v1.0	January 13, 2022 <a href="https://www.intel.com/">https://www.intel.com/</a>	
Intel® Optane™ SSD DC P5811X Series Firmware Version: LD101013	NVMe SSD	Gen4	1.4	M.1	U.1	E.5	NVM	v1.0	January 13, 2022 <a href="https://www.intel.com/">https://www.intel.com/</a>
Kioxia XG8 NVMe SSD	NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	January 11, 2022 <a href="https://www.kioxia.com/en-us/top.html">https://www.kioxia.com/en-us/top.html</a>	
Micron 7450 Firmware Version: M032, E2M0A10, E2M0500	NVMe SSD	Gen4	1.4	1.1	M.2	NVM	v1.0	December 21, 2021 <a href="http://www.micron.com">www.micron.com</a>	
Longsys FORESEE XP2100 Firmware Version: 1.0.1	NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	December 13, 2021 <a href="https://www.longsys.com/">https://www.longsys.com/</a>	
SK Hynix PE8110 Firmware Version: 41090A10	NVMe SSD	Gen4	1.4	1.1b	E.1.5	NVM	v1.0	December 7, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>	
KODIA C07 E3.5 Firmware Version: 0184	NVMe SSD	Gen5	1.4	1.1	E.3.5	NVM	v1.0	November 19, 2021 <a href="https://business.kioxia.com/en-us/news/2021/11/01/011119-2.html">https://business.kioxia.com/en-us/news/2021/11/01/011119-2.html</a>	
TeaFle TC2000 Domestis SSD Firmware Version: TD0C07F	NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	November 16, 2021 <a href="https://www.teafl.com/">https://www.teafl.com/</a>	
Micron 3460 Firmware Version: V12R0A13	BGA NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	November 23, 2021 <a href="http://www.micron.com">www.micron.com</a>	
Solid State Storage Technology C14 NVMe SSD Firmware Version: ET2DQ01	NVMe SSD	Gen4	1.4	NA	M.2	NVM	v1.0	November 17, 2021 <a href="http://www.sstc.com">www.sstc.com</a>	

Western Digital Ultrastar DC ZN40 NVMe Firmware Version: R1Z210009	ZNS NVMe SSD	Gen3	1.3	1.1	U.2		NVM, ZNS	v1.0	November 22, 2021 <a href="http://www.westerndigital.com">www.westerndigital.com</a>
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## NVMe™ Integrator's List v1.0 | NVMe-oF™ Integrator's List

- NVMe Integrator's List Policy v1.0

### NVMe Devices

Product Name + Firmware Version	Product Type	PCIe Gen	NVMe Base Spec Version	Form Factor	Interop Program Revision	Date Listed	Further Info
FADU XSH1121 Firmware Version: Z10040E	NVMe SSD	Gen4	1.4	NA	U.2	v1.0	February 18, 2022 <a href="http://fadutec.com">fadutec.com</a>
FADU XDH1121 Firmware Version: IL2044VE	NVMe SSD	Gen4	1.4	NA	U.2	v1.0	February 18, 2022 <a href="http://fadutec.com">fadutec.com</a>
CNEX Labs CNX 8800CA Firmware Version: FTFR0260	NVMe SSD	Gen4	1.4	NA	U.2	v1.0	November 16, 2021 <a href="http://www.cneelabs.com">www.cneelabs.com</a>
Kioxia B05	NVMe SSD	Gen4	1.4	NA	M.2	v1.0	July 15, 2021 <a href="https://www.kioxia.com/en-us/top.html">https://www.kioxia.com/en-us/top.html</a>
Kioxia X06-AL Firmware Version: 1EALU02A	NVMe SSD	Gen4	1.3	1.1	U.2	v1.0	July 15, 2021 <a href="https://www.kioxia.com/en-us/top.html">https://www.kioxia.com/en-us/top.html</a>
FORESEE F709 Firmware Version: U050680	NVMe SSD	Gen3x4	1.3	NA	M.2 2280	v1.0	July 28, 2021 <a href="http://www.longsys.com/">http://www.longsys.com/</a>
FORESEE F1000 Firmware Version: A010010	NVMe SSD	Gen3x4	1.4	NA	M.2 2280	v1.0	July 28, 2021 <a href="https://www.longsys.com/">https://www.longsys.com/</a>
Intel SSD D5-P5316 NVMe Firmware Version: AC10101	NVMe SSD	Gen4	1.3	1.0	U.2	v1.0	August 2, 2021 <a href="https://www.intel.com/">https://www.intel.com/</a>
SK Hynix PC801 Firmware Version: A0Z0A00	NVMe SSD	Gen4	1.4	NA	M.2	v1.0	July 15, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>
SK Hynix PE8110 Firmware Version: 4110A10	NVMe SSD	Gen4	1.4	NA	E.1.5	v1.0	August 8th, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>
SK Hynix PE8111 Firmware Version: 31281A10	NVMe SSD	Gen3	1.4	NA	E.1.1	v1.0	September 7th, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>
SK Hynix PE1103 Firmware Version: 4109A300	NVMe SSD	Gen4x4	1.4	NA	E.1.5	v1.0	September 20th, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>
SK Hynix BC901 Firmware Version: U01071A	NVMe SSD	Gen4	1.4	NA	M.2	v1.0	August 11th, 2021 <a href="http://www.skhynix.com">www.skhynix.com</a>
Western Digital SN740 Firmware Version: 73030000_73101000_HPS1	NVMe SSD	Gen4	1.4	NA	M.2 2230, 2242, 2280	v1.0	October 5, 2021 <a href="https://www.westerndigital.com/">https://www.westerndigital.com/</a>
Western Digital Ultrastar DC ZN40 NVMe Firmware Version: L4Z07019	NVMe SSD	Gen3	1.3	1.1	U.2	v1.0	July 15, 2021 <a href="https://www.westerndigital.com/">https://www.westerndigital.com/</a>
Western Digital Blue SN750 Firmware Version: Z1A00000_Z1A00000	NVMe SSD	Gen 3x4	1.4	NA	M.2	v1.0	July 15, 2021 <a href="https://www.westerndigital.com/">https://www.westerndigital.com/</a>
Western Digital Green SK530 Firmware Version: Z1A00000_Z1A00000	NVMe SSD	Gen 3x4	1.4	NA	M.2	v1.0	July 15, 2021 <a href="https://www.westerndigital.com/">https://www.westerndigital.com/</a>



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# Agenda

The UNH-IOL and the Beginning of IOL and ICC NVMe<sup>®</sup> Testing

**Test Tool Information**

Testing NVMe Technology

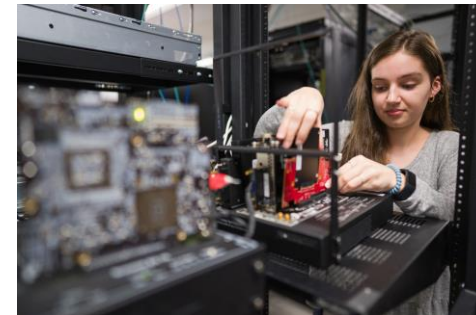
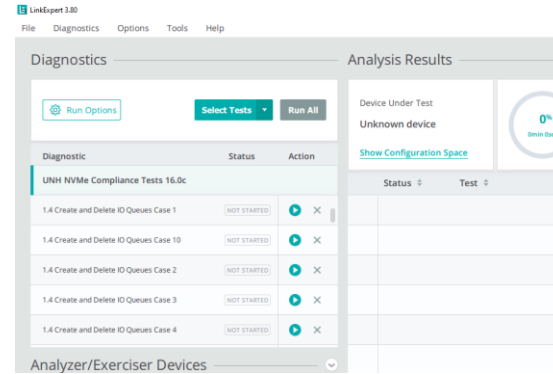
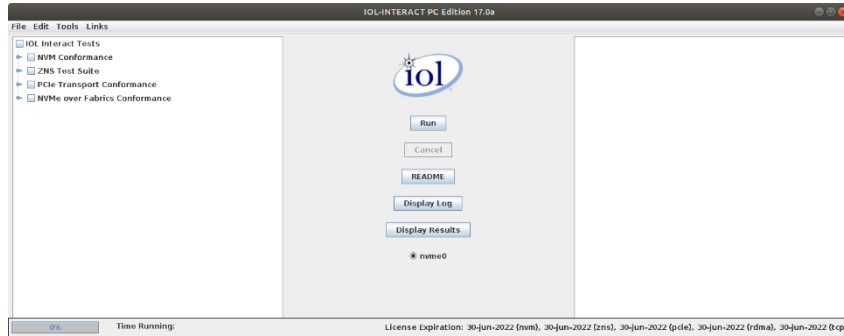
The Refactoring Effort

NVMe 2.0 Specifications and Beyond

Q&A

# The Test Tools

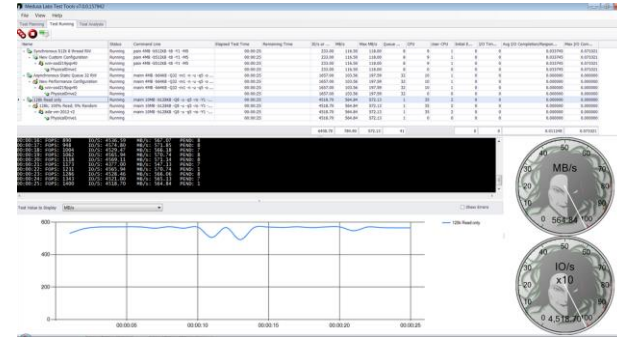
- Conformance testing done with IOL INTERACT PC Edition and LeCroy Edition for automated testing



# The Test Tools

Make	Model	BIOS Version	Operating System	Driver Version	CPU Model
ASRock	ASRock Z270 Extreme4	P2.3	Ubuntu Linux	Inbox Microsoft NVMe Driver	Intel i5-4690K @3.50 GHz
ASRock	ASRock Z97 Extreme 6	P2.3	Ubuntu Linux	Inbox Microsoft NVMe Driver	Intel i5-4690K @3.50 GHz
ASUSTeK Computer Inc.	ASUS ROG STRIX B350-F	0809	Windows 10	Inbox Microsoft NVMe Driver	AMD Ryzen 3 1300X @ 3.50 GHz
ASUSTeK Computer Inc.	ASUS Z170-A	1902	Ubuntu Linux	Linux Kernel NVMe Driver 1.0	Intel Core i5-6500 @ 3.20 GHz
Dell EMC	Dell PowerEdge R740xd	2.3.10	Windows Server 2016	Inbox Microsoft NVMe Driver	Intel Xeon Bronze 3104 CPU @1.7 GHz x 6
Dell, Inc.	Dell PowerEdge R720	2.2.2	Windows Server 2012 R2	Inbox Microsoft NVMe Driver	Intel Xeon CPU E5-2640 @ 2.5GHz
GIGABYTE	AorusElite X570	F36e	Ubuntu Linux		AMD Ryzen 5600G
GIGABYTE	Gigabyte H170 Gaming G3 H170 Gaming G3	F22e	Ubuntu Linux	Linux Kernel 4.4 NVMe Driver 1.0	Intel Core i3-6100 @ 3.7 GHz
Intel Corporation	Intel Server #1 S2600WT (Wildcat Pass)	2.7	Windows 10, Build 10240	Inbox Microsoft NVMe Driver	Intel Xeon CPU E5-2678W v4 @ 3.00 GHz
Intel Corporation	Intel Server #2 S2600WT (Wildcat Pass)	2.7	CentOS 6.7, Kernel 2.6.32	Linux Kernel 2.6.32 NVMe Driver	Intel Xeon CPU E5-2678W v4 @ 3.00 GHz

- Interoperability testing completed with a variety of hosts, traffic generators, and hot plug testing capabilities from Quarch tools



## Vdbench Users Guide

Version: 5.04.07

May 2018

Author: Henk Vandenberg



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# Agenda

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**Testing NVMe Technology**

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Q&A

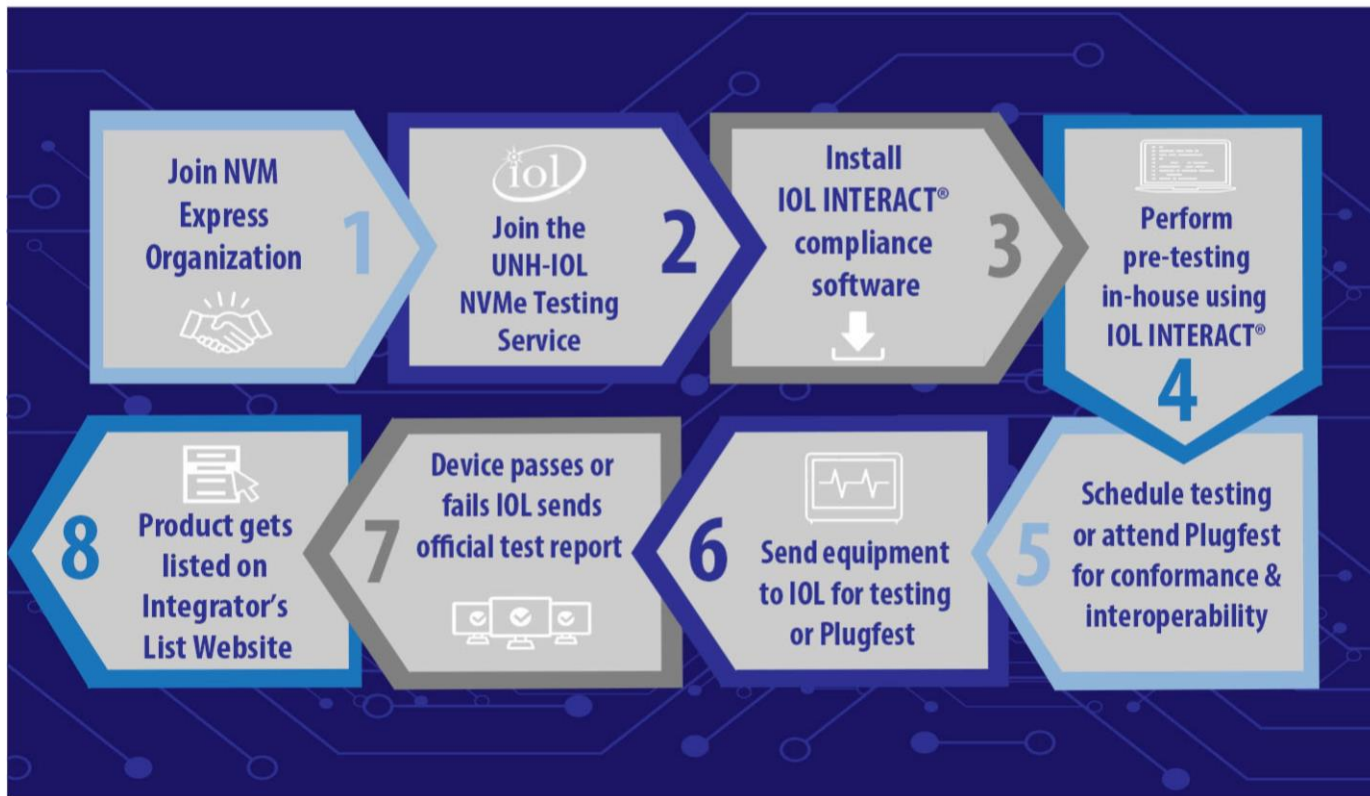


# NVMe<sup>®</sup> and NVMe-oF<sup>™</sup> Plugfests



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# Early NVMe<sup>®</sup> Specifications Testing

- NVMe PCIe<sup>®</sup> SSD testing requires
  - Conformance
  - Interoperability
- NVMe-oF<sup>™</sup> Target testing requires
  - Conformance
  - Interoperability
- NVMe-oF<sup>™</sup> Initiator and Switch testing is only interoperability

Device Type	Conformance	Interoperability
NVMe Storage Device	√	√
NVMe Host Platform		√
NVMe-oF <sup>™</sup> Target	√	√
NVMe-oF <sup>™</sup> Initiator		√
NVMe-oF <sup>™</sup> Switch		√



# Conformance Testing

Testing cutting edge features, new to the industry

Both test tool and feature application being tested

Failing results are not always a bad thing

Issues at this stage can be fixed

Trends of Features being Implemented

Never a shortage of TPs, but which ones are being implemented



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# Interoperability Testing

Will the product work in various environments?

Recent Issues of Unique Identifiers

PCIe vs Other Transports complexity



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# Agenda

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Test Tool Information

Testing NVMe Technology

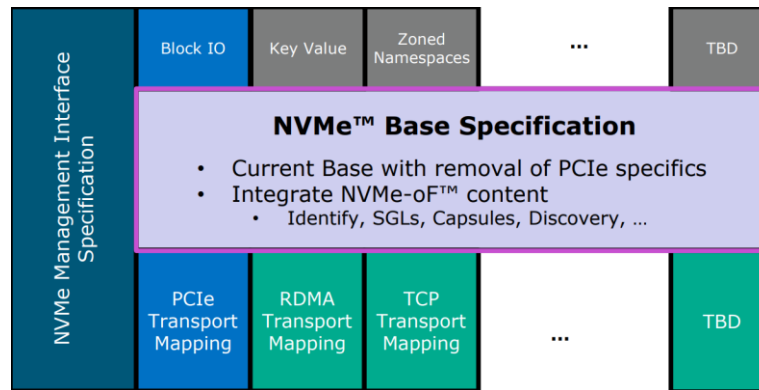
**The Refactoring Effort**

NVMe 2.0 Specifications and Beyond

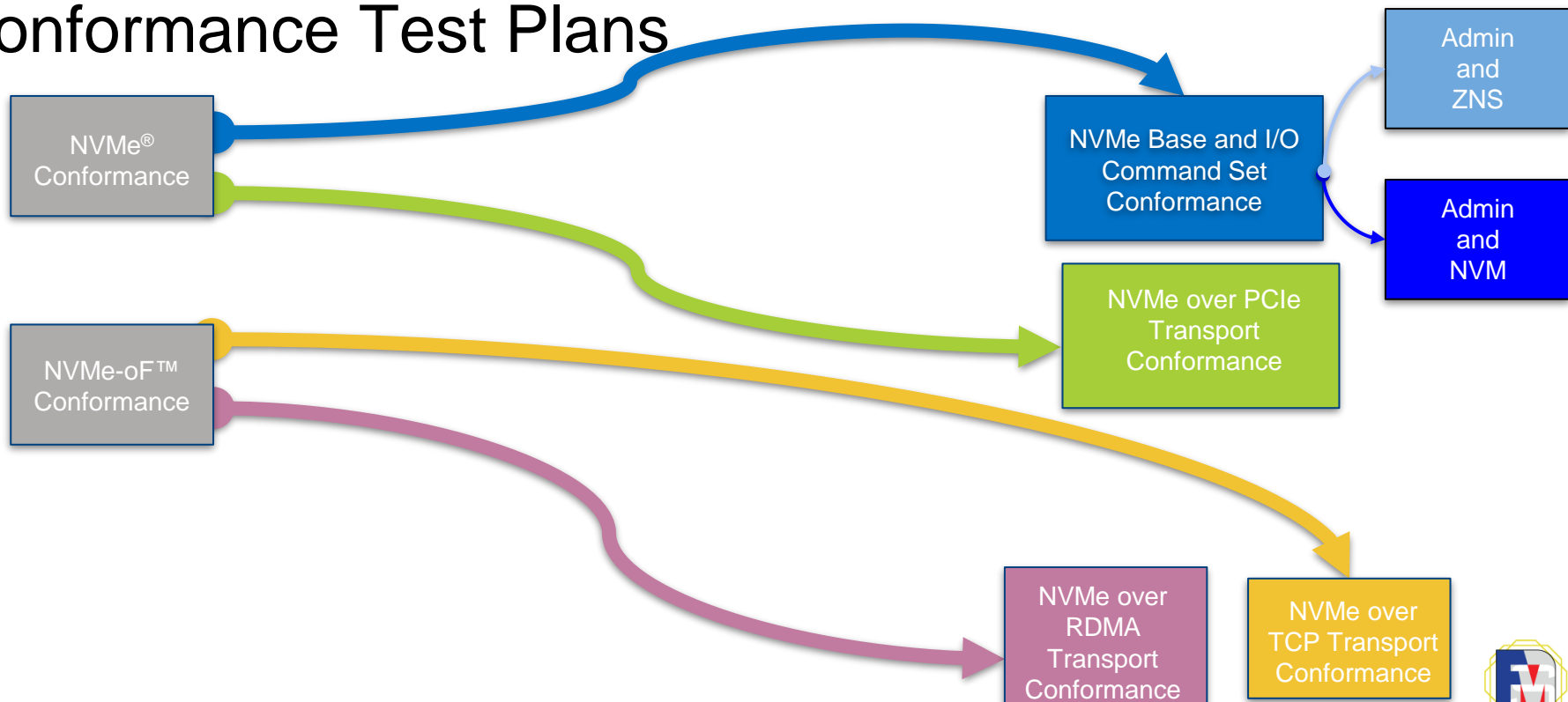
Q&A

# The Refactoring Effort

- Why the Refactor?
- “A simplified format, easing the development of NVMe technology and allowing for rapid innovation.”
  - Create scalable specification intrastate to allow further growth of NVMe<sup>®</sup> technology as it becomes more common in storage applications
- Test plan changes required



# Changes in the Conformance Test Plans



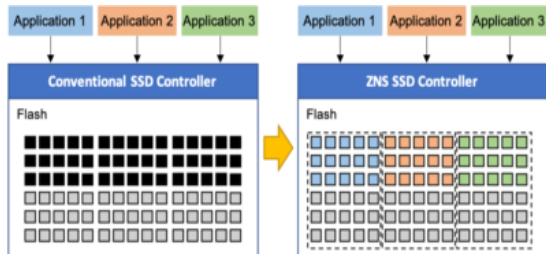
# New Command Set Specifications

## Command Sets Defined

Zoned Namespace Command Set

NVM Command Set

Key Value Command Set



## Upcoming Command Sets for Test

Computational Programs

## Transports Defined

PCIe

TCP

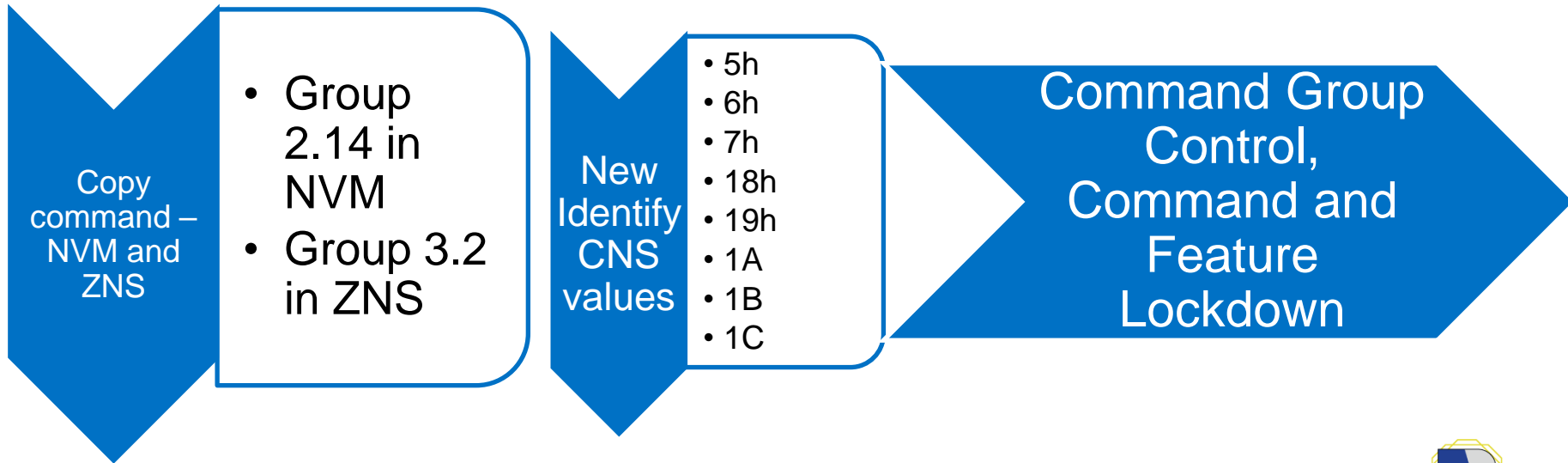
RDMA/iWARP



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# NVMe<sup>®</sup> 2.0 Specification New Features: Currently Testing in Test Plan 17





# NVMe<sup>®</sup> 2.0 Specification New Features: To Be Tested in Test Plan 18

Endurance Group  
Management

TP4052c: 48 New Tests

New Log Page  
Index Offsets

TP4075a: 9 New Tests

Namespace  
Capability  
Reporting

TP4095: 7 New Tests

Host Specifying  
Telemetry Host-  
Initiated Data Area

TP4109: 3 New Tests



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# NVMe<sup>®</sup> Testing Now

389 Tests in NVM Conformance Test Plan

265 Tests in ZNS Conformance Test Plan

107 Tests in MI Test Plan

29 Tests in RDMA Transport Conformance Test Plan

43 Tests in TCP Transport Conformance Test Plan

16 Tests in Interoperability Suites (PCIe and oF)

**849 Total Tests**



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The UNH-IOL and the Beginning of IOL and ICC NVMe<sup>®</sup> Testing

Test Tool Information

Testing NVMe Technology

The Refactoring Effort

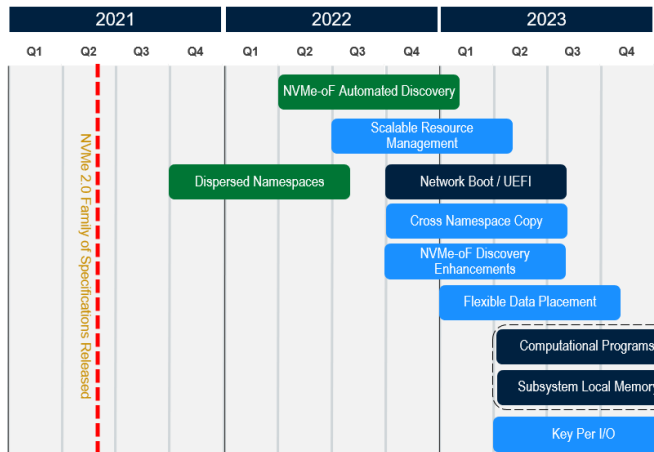
**NVMe 2.0 Specifications and Beyond**

Q&A

# Future Testing Items

NVMe<sup>®</sup> 2.0 specifications and beyond

Based on the NVM Express<sup>®</sup> Road Map



Computational Programs

Key Per IO

Cross Namespace Copy

NVMe-oF<sup>™</sup> Discovery Automation

# The Overarching Goal is Confidence in the NVMe<sup>®</sup> Product

- When all devices are conformant, **the storage industry performs better**
- All caught issues are communicated such that they can be **resolved prior to market release**
- The UNH-IOL and ICC work directly with the TWG to test the most important and widely adopted features
- Your customers can see **standardized reports** showing which features are supported and conformant to the specification
- **Certify with confidence** that the product conforms to the applicable NVMe<sup>®</sup> specifications



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# Questions?



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