



NVM Express®

Zoned Namespace Command Set Specification

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Please send comments to info@nvme.org

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1 Introduction

1.1 Overview

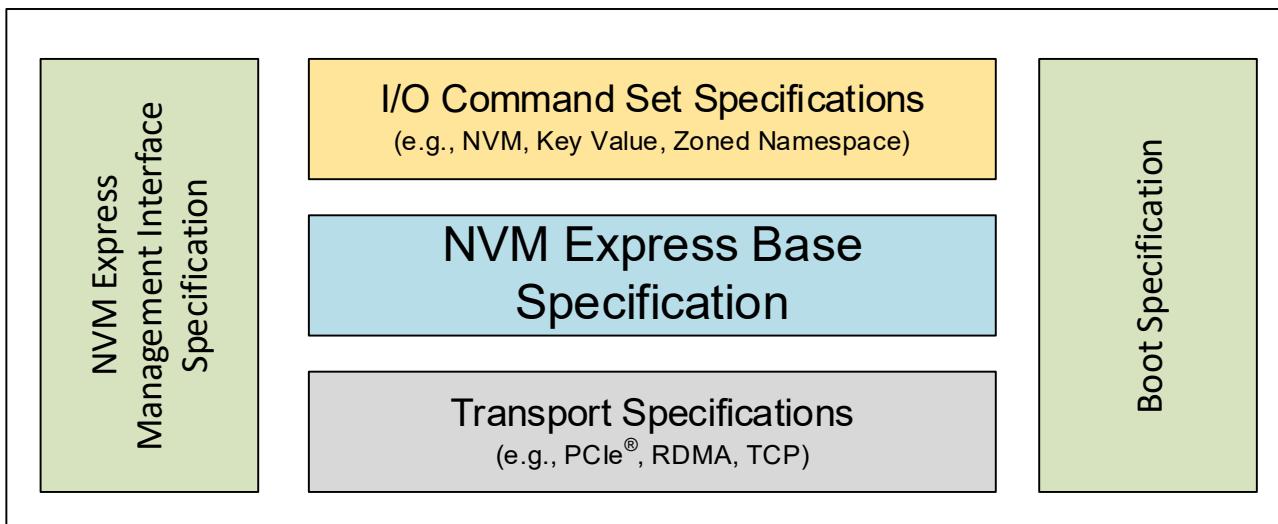
The NVM Express® (NVMe®) Base Specification defines an interface for a host to communicate with a non-volatile memory subsystem (NVM subsystem) over a variety of memory-based transports and message-based transports.

This document defines a specific NVMe I/O Command Set, the Zoned Namespace Command Set, which extends the NVM Express Base Specification and the NVM Command Set Specification.

1.2 Scope

Figure 1 shows the relationship of the NVM Express® Zoned Namespace Command Set Specification to other specifications within the NVMe Family of Specifications.

Figure 1: NVMe Family of Specifications



This specification supplements the NVM Express Base Specification. This specification defines additional data structures, features, log pages, commands, and status values. This specification also defines extensions to existing data structures, features, log pages, commands, and status values. This specification defines requirements and behaviors that are specific to the Zoned Namespace Command Set. Functionality that is applicable generally to NVMe or that is applicable across multiple I/O Command Sets is defined in the NVM Express Base Specification.

If a conflict arises among requirements defined in different specifications, then a lower-numbered specification in the following list shall take precedence over a higher-numbered specification:

1. Non-NVMe specifications
2. NVM Express Base Specification
3. NVM Express Transport specifications
4. NVM Express I/O Command Set specifications
5. NVM Express Management Interface Specification
6. NVM Express Boot Specification

1.3 Conventions

This specification conforms to the Conventions section, Keywords section, and Byte, Word, and Dword Relationships section of the NVM Express Base Specification.

1.4 Definitions

1.4.1 Definitions from the NVM Express Base Specification

This specification uses the definitions in the NVM Express Base Specification.

1.4.2 Terms in the NVM Express Base Specification specified in the Zoned Namespace Command Set

The following terms used in this specification and the NVM Express Base Specification are as defined in this section.

1.4.2.1 Endurance Group Host Read Command

An Endurance Group Host Read Command as defined in the NVM Command Set Specification.

1.4.2.2 Format Index

A value used to index into the LBA Formats list (refer to the NVM Command Set Specification), the Extended LBA Formats list (refer to the NVM Command Set Specification), and the LBA Format Extensions list (refer to Figure 49).

1.4.2.3 Identify Controller data structures

All controller data structures that are able to be retrieved via the Identify command for the Zoned Namespace Command Set:

- the Identify Controller data structure (refer to the NVM Express Base Specification);
- the I/O Command Set specific Identify Controller data structure for the NVM Command Set (refer to the NVM Command Set Specification); and
- the I/O Command Set specific Identify Controller data structure for the Zoned Namespace Command Set (refer to section 4.1.5.2).

1.4.2.4 Identify Namespace data structures

All namespace data structures that are able to be retrieved via the Identify command for the Zoned Namespace Set (refer to section 4.1.5.4 for specific field settings for the Identify command):

- the I/O Command Set Independent Identify Namespace data structure (refer to the NVM Express Base Specification);
- Identify Namespace data structure (refer to NVM Command Set Specification);
- the I/O Command Set specific Identify Namespace data structure for the NVM Command Set (refer to section NVM Command Set Specification); and
- the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set (refer to section 4.1.5.1).

1.4.2.5 SMART Data Units Read Command

A SMART Data Units Read Command as defined in the NVM Command Set Specification.

1.4.2.6 SMART Host Read Command

A SMART Host Read Command as defined in the NVM Command Set Specification.

1.4.2.7 User Data Out Command

A User Data Out Command as defined in the NVM Command Set Specification and the Zone Append command.

1.4.3 Definitions from the NVM Command Set Specification

The following terms are defined in the NVM Command Set Specification and are used in this specification:

- a) LBA range
- b) logical block
- c) logical block address (LBA)
- d) User Data Format

1.4.4 Definitions specific to the Zoned Namespace Command Set

This section defines terms that are specific to this specification.

1.4.4.1 active zone

A zone that is in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state.

1.4.4.2 Address-Specific Write Command

A Write command, Write Uncorrectable command, Write Zeroes command, or Copy command. Address-Specific Write Commands specify a range of logical block addresses in command parameters as part of the submission queue entry or in data structures pointed to by the command parameters.

1.4.4.3 Ceiling

A function where, for real number x , $\text{ceiling}(x)$ is equal to x rounded up to the nearest integer value. If x is an integer then $\text{ceiling}(x)$ is equal to x .

1.4.4.4 open zone

A zone that is in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state.

1.4.4.5 write operation

An operation initiated by a Write command, a Write Zeroes command, a Write Uncorrectable command, a Copy command, or a Zone Append command.

1.4.4.6 zone

A contiguous range of logical block addresses that are managed as a single unit.

1.4.4.7 Zone Descriptor

The data structure that contains information about a zone.

1.4.4.8 Zone Descriptor Extension

Host defined data that is associated with a zone.

1.4.4.9 zoned namespace

A namespace that is divided into zones and is associated with the Zoned Namespace Command Set.

1.4.4.10 Zone Random Write Area (ZRWA)

An area of non-volatile medium with a sliding set of assigned LBAs which start at the write pointer for the associated zone.

1.5 References

NVM Express® Base Specification, Revision 2.3. Available from <https://www.nvmexpress.org>.

NVMe® NVM Command Set Specification, Revision 1.2. Available from <https://www.nvmexpress.org>.

2 Zoned Namespace Command Set Model

The NVM Express Base Specification defines an interface for a host to communicate with a non-volatile memory subsystem (NVM subsystem). This specification defines additional functionality for the Zoned Namespace Command Set.

The Command Set Identifier (CSI) value for this Command Set is 02h.

2.1 Theory of operation

This section defines the operation of the Zoned Namespace Command Set.

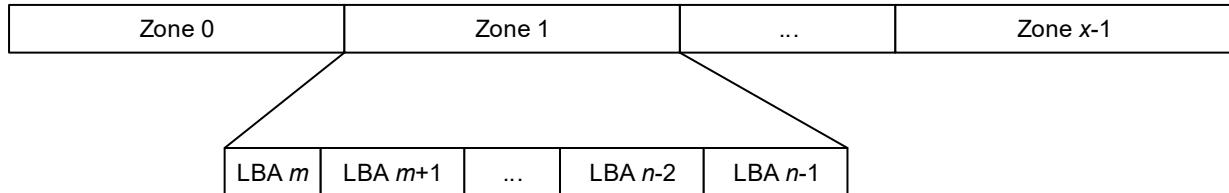
2.1.1 Namespaces

A namespace is a set of resources that may be accessed by a host and is defined in the NVM Express Base Specification and in the NVM Command Set Specification, as modified by this specification. A namespace has an associated namespace identifier that a host uses to access that namespace.

A zoned namespace is a namespace that is associated with the Zoned Namespace Command Set. A zoned namespace is divided into a set of equally-sized zones, which are contiguous non-overlapping ranges of logical block addresses. Figure 2 shows a zoned namespace with x zones and z LBAs where LBA 0 is the lowest LBA of zone 0, LBA $z-1$ is the highest LBA of zone $x-1$, and for Zone 1, m is the lowest LBA and $n-1$ is its highest LBA.

Figure 2: Zones in a Zoned Namespace

Zone 0		Zone 1		...	Zone $x-1$
LBA 0	LBA 1			...	LBA $z-1$



The Zoned Namespace Command Set is based on the NVM Command Set (refer to the NVM Command Set Specification).

Each zone has an associated Zone Descriptor that contains a set of attributes. A Zone Management Receive command may be used to retrieve one or more Zone Descriptors.

2.1.1.1 Zone Descriptor

The attributes associated with a zone are summarized in Figure 3. These attributes are reported in the Zone Descriptor data structure as defined in Figure 38.

Figure 3: Summary of Zone Descriptor Attributes

Attribute	Description	
Zone Type	The zone type attribute defines the rules for reading and writing to a zone.	
	Zone Type	Reference Section
	Sequential Write Required	2.1.1.2.1

Figure 3: Summary of Zone Descriptor Attributes

Attribute	Description		
	Zone Type	Zone State	Reference Section
Zone State	Sequential Write Required	ZSE:Empty	2.1.1.3.1
		ZSIO:Implicitly Opened	2.1.1.3.2
		ZSEO:Explicitly Opened	2.1.1.3.3
		ZSC:Closed	2.1.1.3.4
		ZSF:Full	2.1.1.3.5
		ZSRO:Read Only	2.1.1.3.6
		ZSO:Offline	2.1.1.3.7
Write Pointer	The Write Pointer attribute defines the lowest numbered writeable logical block address in that zone. The validity of the write pointer is zone state specific and is defined per zone type (refer to section 2.1.1.2).		
Zone Start Logical Block Address	The Zone Start Logical Block Address (ZSLBA) attribute defines the lowest logical block address for that zone.		
Zone Capacity	The Zone Capacity attribute defines the writeable capacity of that zone.		
Zone Descriptor Extension Valid	The Zone Descriptor Extension Valid attribute defines the validity of the Zone Descriptor Extension data of that zone. Refer to section 5.3.		
Reset Zone Recommended	The Reset Zone Recommended attribute indicates that the controller recommends that the host resets that zone. Refer to section 5.4.		
Finish Zone Recommended	The Finish Zone Recommended attribute indicates that the controller recommends that the host finishes that zone. Refer to section 5.5.		
Zone Finished by Controller	The Zone Finished by Controller attribute indicates that the controller finished that zone due to a Zone Active Excursion. Refer to section 5.6.		

2.1.1.2 Zone Types

2.1.1.2.1 Sequential Write Required Zones

A zone type of Sequential Write Required requires the set of logical block addresses of a zone to be written sequentially.

2.1.1.2.1.1 Writing in Sequential Write Required Zones

The following commands may be used to write to logical blocks in a specific zone of zone type Sequential Write Required:

- Write command;
- Write Zeroes command;
- Write Uncorrectable command;
- Copy command; and
- Zone Append command, if no ZRWA is associated with the zone.

A write pointer is maintained for each zone in the zoned namespace that indicates the lowest-numbered writeable logical block address in that zone. The write pointer is valid for a subset of the zone states as defined in Figure 4.

Figure 4: Zone Characteristics

State	Zone Characteristics		
	Valid Write Pointer ¹	Active Resources ²	Open Resources ²
ZSE:Empty	Yes	No	No
ZSIO:Implicitly Opened	Yes	Yes	Yes
ZSEO:Explicitly Opened	Yes	Yes	Yes
ZSC:Closed	Yes	Yes	No
ZSF:Full	No	No	No
ZSRO:Read Only	No	No	No

Figure 4: Zone Characteristics

State	Zone Characteristics		
	Valid Write Pointer ¹	Active Resources ²	Open Resources ²
ZSO:Offline	No	No	No
Notes:			
1. A valid write pointer (i.e., Yes) indicates that the Write Pointer field in the Zone Attributes field for that zone contains a valid logical block address. An invalid write pointer (i.e., No) provides no information.			
2. Resources associated with a zone are defined in section 2.1.1.4.			

The host may use the Zone Management Receive command to determine the current write pointer for a zone.

The Zone Management Send command with a Zone Send Action of Reset Zone sets the write pointer to the ZSLBA for that zone.

Figure 5 shows an example of a zone in the ZSE:Empty state. LBA m is the ZSLBA attribute, the write pointer indicates ZSLBA, and n-1 is the highest LBA of the zone.

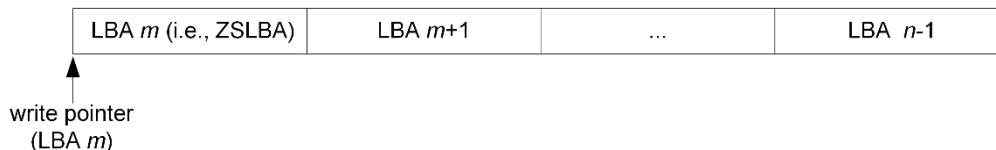
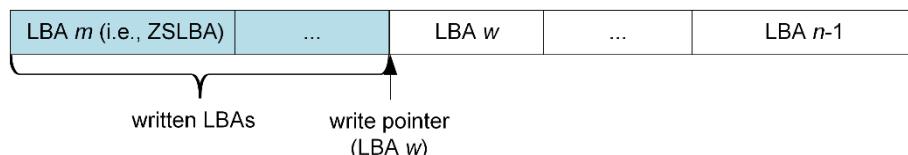
Figure 5: Write Pointer in an Empty Zone

Figure 6 shows an example of a zone in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state, that has had one or more logical blocks written. The write pointer, indicated by LBA w, is the lowest-numbered writeable LBA and n-1 is the highest-numbered LBA of the zone.

Figure 6: Write Pointer in a Partially Written Zone

The controller shall abort a command that writes to a zone that is in the ZSF:Full state with a status code of Zone Is Full.

The controller shall abort a command that writes to a zone that is in the ZSRO:Read Only state, with a status code of Zone Is Read Only.

The controller shall abort a command that writes to a zone that is in the ZSO:Offline state, with a status code of Zone Is Offline.

For a zone associated with a ZRWA (refer to section 5.7), commands shall be processed as defined in section 5.7.

For a zone not associated with a ZRWA and which has a valid write pointer, commands shall be processed as follows:

- a) if the controller:
 - a. successfully writes to all logical blocks specified by a write operation, then the write pointer shall be increased by the number of logical blocks written on successful completion of that write operation; and

- b. is not able to successfully write to all logical blocks specified by a write operation, then the write pointer shall:
 - i. be set to a value within the range of LBAs specified in that write operation;
 - ii. be set to one greater than the last LBA in the range of LBAs specified in that write operation; or
 - iii. become invalid (i.e., due to transitioning to the ZSRO:Read Only state or the ZSO:Offline state, or due to a Zone Active Excursion (refer to section 5.6));
- b) if an Address-Specific Write Command specifies a Starting LBA field that is not equal to the write pointer for that zone, then the controller shall abort that command with a status code of Zone Invalid Write; and
- c) if a Zone Append command specifies a ZSLBA that is not the lowest logical block address in that zone, then the controller shall abort that command with a status code of Invalid Field in Command, as described in section 3.4.1.

The controller shall abort a command that initiates a write operation that has a starting LBA in one zone, and for which the Number of Logical blocks exceeds the remaining number of logical blocks in that zone, with a status code of Zone Boundary Error.

2.1.1.2.1.2 Reading in Sequential Write Required Zones

If the zone for a User Data Read Access Command is:

- a) in the ZSO:Offline state, then that command shall be aborted with a status code of Zone Is Offline; or
- b) in any other state, then that User Data Read Access Command is performed as described in this section, in section 2.1.1.5, and in the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification.

If the Read Across Zone Boundaries bit is set to '1' in the Zoned Namespace Command Set specific Identify Namespace data structure (refer to Figure 49), then User Data Read Access Commands are allowed to specify an LBA range containing logical blocks in more than one zone.

If the Read Across Zone Boundaries bit is cleared to '0', then commands that perform read operations that specify an LBA range containing logical blocks in more than one zone shall be aborted with a status code of Zone Boundary Error.

2.1.1.3 Zone State Machine

There is a state machine associated with each zone. A zone state machine controls the operational characteristics of a zone. A zone state machine consists of the following states: ZSE:Empty, ZSIO:Implicitly Opened, ZSEO:Explicitly Opened, ZSC:Closed, ZSF:Full, ZSRO:Read Only, and ZSO:Offline.

The initial state of a zone state machine is set as a result of:

- a) an NVM Subsystem Reset; or
- b) all controllers in the NVM subsystem reporting controller shutdown processing complete (i.e., the Shutdown Type (ST) bit cleared to '0' and the Shutdown Status (SHST) field set to 10b, refer to the NVM Express Base Specification).

The initial state for each zone is the:

- a) ZSE:Empty state if:
 - 1. the write pointer is valid;
 - 2. the write pointer points to the lowest LBA in the zone;
 - 3. the Zone Descriptor Extension Valid bit is cleared to '0'; and
 - 4. the ZRWA, if any, associated with the zone contains no user data;
- b) ZSC:Closed state if the write pointer is valid and:
 - 1. the write pointer does not point to the lowest LBA in the zone;
 - 2. the Zone Descriptor Extension Valid bit is set to '1'; or
 - 3. the ZRWA, if any, associated with the zone contains user data;

c) ZSF:Full state if:

1. the most recent state was the ZSF:Full; or
2. the zone state was transitioned to the ZSF:Full state as a result of the NVM Subsystem Reset;

- d) ZSRO:Read Only state, if the most recent zone state was the ZSRO:Read Only state; and
- e) ZSO:Offline state, if the most recent zone state was the ZSO:Offline state.

The initial zone state for each zone upon a successful sanitize operation is defined in section 5.8.

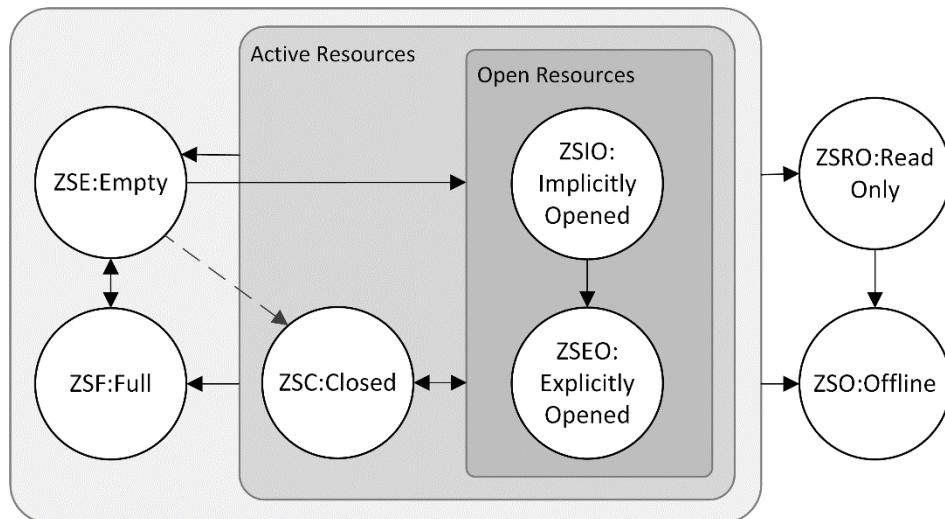
Transitions between zone states cause reporting of a Zone Descriptor Changed asynchronous event as defined in Figure 43.

If the zoned namespace is formatted with a Format NVM command or created with a Namespace Management command, the zones in the zoned namespace are initialized to either the ZSE:Empty state or the ZSO:Offline state.

Zones that are in the ZSE:Empty state, the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, the ZSC:Closed state, or the ZSF:Full state may transition to the ZSRO:Read Only state or the ZSO:Offline state by mechanisms outside the scope of this specification.

Figure 7 shows the valid transitions between each zone state from the time a zoned namespace is formatted or created. The transition (dotted line) from the ZSE:Empty state to the ZSC:Closed state is only valid when the zoned namespace is formatted with Zone Descriptor Extension support (refer to section 5.3). An arrow to or from a shaded area indicates transitions to or from all states in that area.

Figure 7: Zone State Machine



The processing of a command may cause multiple transitions in one or more zone state machines (e.g., the processing of a Write command may cause a transition from the ZSC:Closed state to the ZSIO:Implicitly Opened state and then cause a transition from the ZSIO:Implicitly Opened state to the ZSF:Full state).

2.1.1.3.1 ZSE:Empty state

Transition ZSE:ZSIO: The zone shall transition from the ZSE:Empty state to the ZSIO:Implicitly Opened state if there are available resources as defined in section 2.1.1.4 and a write operation writes one or more logical blocks of that zone.

Transition ZSE:ZSEO: The zone shall transition from the ZSE:Empty state to the ZSEO:Explicitly Opened state if there are available resources as defined in section 2.1.1.4 and a Zone Management Send command with a Zone Send Action of Open Zone completes successfully.

Transition ZSE:ZSC: The zone shall transition from the ZSE:Empty state to the ZSC:Closed state if there are available active resources as defined in section 2.1.1.4 and a Zone Management Send command with a Zone Send Action of Set Zone Descriptor Extension completes successfully.

Transition ZSE:ZSF: The zone shall transition from the ZSE:Empty state to the ZSF:Full state as a result of a Zone Management Send command with a Zone Send Action of Finish Zone completes successfully.

2.1.1.3.2 ZSIO:Implicitly Opened state

Transition ZSIO:ZSE: The zone shall transition from the ZSIO:Implicitly Opened state to the ZSE:Empty state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Reset Zone.

Transition ZSIO:ZSEO: The zone shall transition from the ZSIO:Implicitly Opened state to the ZSEO:Explicitly Opened state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Open Zone.

Transition ZSIO:ZSC: The zone shall transition from the ZSIO:Implicitly Opened state to the ZSC:Closed state as a result of:

- a) successful completion of a Zone Management Send command with a Zone Send Action of Close Zone; and
- b) the controller initiating the transition as defined in section 2.1.1.4.1.

Transition ZSIO:ZSF: The zone shall transition from the ZSIO:Implicitly Opened state to the ZSF:Full state:

- a) as a result of successful completion of a Zone Management Send command with a Zone Send Action of Finish Zone;
- b) as a result of a write operation that writes one or more logical blocks that causes the zone to reach its writeable zone capacity;
- c) due to a Zone Active Excursion (refer to section 5.6); and
- d) as a result of the zoned namespace becoming write protected (refer to the Namespace Write Protection section in the NVM Express Base Specification).

2.1.1.3.3 ZSEO:Explicitly Opened state

Transition ZSEO:ZSE: The zone shall transition from the ZSEO:Explicitly Opened state to the ZSE:Empty state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Reset Zone.

Transition ZSEO:ZSC: The zone shall transition from the ZSEO:Explicitly Opened state to the ZSC:Closed state upon successful completion of a Zone Management Send command with a Zone Send Action of Close Zone.

Transition ZSEO:ZSF: The zone shall transition from the ZSEO:Explicitly Opened state to the ZSF:Full state:

- a) as a result of successful completion of a Zone Management Send command with a Zone Send Action of Finish Zone;
- b) as a result of a write operation that writes one or more logical blocks that causes the zone to reach its writeable zone capacity;
- c) due to a Zone Active Excursion (refer to section 5.6); or
- d) as a result of the zoned namespace becoming write protected (refer to the Namespace Write Protection section in the NVM Express Base Specification).

2.1.1.3.4 ZSC:Closed state

Transition ZSC:ZSE: The zone shall transition from the ZSC:Closed state to the ZSE:Empty state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Reset Zone.

Transition ZSC:ZSIO: The zone shall transition from the ZSC:Closed state to the ZSIO:Implicitly Opened state, if there are available resources as defined in section 2.1.1.4 and:

- a) a write operation writes one or more logical blocks of that zone; or

- b) an explicit ZRWA Flush operation is completed.

Transition ZSC:ZSEO: The zone shall transition from the ZSC:Closed state to the ZSEO:Explicitly Opened state if there are available resources as defined in section 2.1.1.4 and a Zone Management Send command with a Zone Send Action of Open Zone completes successfully.

Transition ZSC:ZSF: The zone shall transition from the ZSC:Closed state to the ZSF:Full state:

- a) as a result of successful completion of a Zone Management Send command with a Zone Send Action of Finish Zone;
- b) due to a Zone Active Excursion (refer to section 5.6); and
- c) as a result of the zoned namespace becoming write protected (refer to the Namespace Write Protection section in the NVM Express Base Specification).

2.1.1.3.5 ZSF:Full state

Transition ZSF:ZSE: The zone shall transition from the ZSF:Full state to the ZSE:Empty state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Reset Zone.

2.1.1.3.6 ZSRO:Read Only state

Transition ZSRO:ZSO: The zone shall transition from the ZSRO:Read Only state to the ZSO:Offline state as a result of successful completion of a Zone Management Send command with a Zone Send Action of Offline Zone.

2.1.1.3.7 ZSO:Offline state

There are no transitions from the ZSO:Offline state to any other zone state.

2.1.1.4 Zone Resources

Zones may have associated Active Resources, associated Open Resources, and associated ZRWA resources. The resources limit the number of zones that are allowed to be in each zone state. The resource relationship is defined in Figure 8.

Figure 8: Zone Resources

Resource	States	Comment
Active	ZSIO:Implicitly Opened, ZSEO:Explicitly Opened, ZSC:Closed	Zones in zone states associated with this resource are limited by the Maximum Active Resources field.
Open	ZSIO:Implicitly Opened, ZSEO:Explicitly Opened	Zones in zone states associated with this resource are limited by the Maximum Open Resources field.
ZRWA	ZSIO:Implicitly Opened, ZSEO:Explicitly Opened, ZSC:Closed	Zones in zone states associated with this resource are limited by the Number of ZRWA Resources field. Refer to section 5.7.

Zones that have associated Open Resources are a subset of the zones that are associated with Active Resources. The Maximum Open Resources field shall be less than or equal to the Maximum Active Resources field in the I/O Command Set specific Identify Namespace Data Structure for the Zoned Namespace Command Set (refer to Figure 49).

If the ZRWA Supported bit is set to ‘1’ in the OZCS field in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set, then the Number of ZRWA Resources field in that data structure shall be less than or equal to the Maximum Active Resources field in that data structure.

2.1.1.4.1 Managing resources

The controller associates Active Resources with zones in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, and the ZSC:Closed state. The controller associates Open Resources with zones in the ZSIO:Implicitly Opened state and the ZSEO:Explicitly Opened state.

Resource management for active and open resources is as follows:

- a) A transition from the ZSE:Empty state to the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state increases the resource usage of Active Resources and Open Resources by 1.
- b) A transition from the ZSE:Empty state to the ZSC:Closed state increases the resource usage of Active Resources by 1.
- c) A transition from the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state to the ZSC:Closed state decreases the resource usage of Open Resources by 1.
- d) A transition from the ZSC:Closed state to the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state increases the resource usage of Open Resources by 1.
- e) A transition from the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state to the ZSE:Empty state, the ZSF:Full state, the ZSRO:Read Only state, or the ZSO:Offline state decreases the resource usage of Active Resources and Open Resources by 1.
- f) A transition from the ZSC:Closed state to the ZSE:Empty state, the ZSF:Full state, the ZSRO:Read Only state, or the ZSO:Offline state decreases the resource usage of Active Resources by 1.
- g) A transition from the ZSE:Empty state to the ZSF:Full state shall not impact resource usage of Active Resources and Open Resources.

A controller processing a command that requests a zone to transition to the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state shall, if resources are not available and:

- a) the Maximum Active Resources field is greater than the Maximum Open Resources field and:
 - i. as a result of the requested transition the resource that is not available is Active Resources, then abort the command with a status code of Too Many Active Zones; or
 - ii. as a result of the requested transition the resource that is not available is Open Resources, and:
 - a. one or more zones are in the ZSIO:Implicitly Opened state, then the controller shall select one of the zones in the ZSIO:Implicitly Opened state, transition that zone to the ZSC:Closed state, and proceed to process the command; or
 - b. no zones are in the ZSIO:Implicitly Opened state, then the controller shall abort the command with a status code of Too Many Open Zones;
- or
- b) the Maximum Active Resources field is equal to the Maximum Open Resources field and as a result of the requested transition the resource that is not available is Active Resources, then abort the command with a status code of Too Many Active Zones.

If the ZRWA Supported bit is set to '1' in the OZCS field in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set, then as described in Figure 8, the controller associates ZRWA Resources with zones in the ZSIO:Implicitly Opened, the ZSEO:Explicitly Opened, and the ZSC:Closed states.

Resource management for ZRWA Resources is as follows:

- a) A successful allocation of a ZRWA to a zone as a result of the Zone Management Send command (refer to section 3.4.3) increases the resource usage of ZRWA Resources by 1.
- b) For a zone with an associated ZRWA Resource, a transition to the ZSE:Empty state, the ZSF:Full state, the ZSRO:Read Only state, or the ZSO:Offline state decreases the resource usage of ZRWA Resources by 1.

A controller that supports ZRWA resources and that processes a command that requests a ZRWA Resource shall, if ZRWA Resources are not available due to the number of ZRWA Resources in use being equal to the Number of ZRWA Resources field, abort that command with a status code of ZRWA Resources Unavailable.

Zones that have associated Active Resources are transitioned to the ZSF:Full state when the zoned namespace becomes write protected. Refer to the Namespace Write Protection section in the NVM Express Base Specification.

The coordination of host usage of resources associated with shared zoned namespaces is outside the scope of this specification.

2.1.1.5 Logical Block Allocation and Capacity Management

A logical block shall be marked as allocated when that logical block is written with:

- a) a Write command;
- b) a Write Uncorrectable command;
- c) a Write Zeroes command that does not deallocate the logical block (refer to the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification);
- d) a Copy command;
- e) a Zone Append command; and
- f) any other command specified by the NVM Command Set Specification as marking a logical block as allocated.

A logical block may be marked as allocated as the result of:

- a) a Write command not addressing that logical block (e.g., a write of LBA n causes allocation of LBAs n and n+1);
- b) a Write Uncorrectable command not addressing that logical block;
- c) a Write Zeroes command not addressing that logical block (refer to the Write Zeroes command in the NVM Command Set Specification);
- d) a Copy command not addressing that logical block;
- e) a Zone Management Send command that transitions a zone containing that logical block to the ZSEO:Explicitly Opened state or the ZSC:Closed state;
- f) a Zone Append command; and
- g) any other command specified by the NVM Command Set Specification that may mark a logical block as allocated.

A logical block may be marked deallocated as the result of:

- a) a Dataset Management command;
- b) a Write Zeroes command addressing that deallocates logical blocks (refer to the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification);
- c) a sanitize operation;
- d) a Format NVM command; and
- e) any other command specified by the NVM Command Set Specification that may mark a logical block as deallocated.

All logical blocks in a zone shall be marked as deallocated when the zone is in the ZSE:Empty state.

2.1.2 Command Ordering Requirements

Commands submitted to a zoned namespace are processed as specified in the NVM Express Base Specification and in the NVM Command Set Specification. As described in the NVM Command Set Specification, the controller is not responsible for checking the LBA of an Address-specific Write command to ensure any type of ordering between commands. For example, if an Address-specific Write command is submitted for LBA x and an Address-specific Write command is also submitted for LBA x + 1, there is no guarantee of the order of processing for those commands. If there are ordering requirements between these commands (e.g., zone type), the host is required to enforce that ordering during the submission of each of those commands.

2.1.3 Fused Operation

No fused operations are supported for this specification (e.g., the fused operations defined in the NVM Command Set Specification are not supported for this specification).

2.1.4 Atomic Operation

The AWUN, NAWUN, NABSN, AWUPF, NAWUPF, NABSPF atomicity parameters apply as defined in the Atomic Operations section in the NVM Command Set Specification.

2.1.5 End-to-end Protection Information

End-to-end protection information operates as defined in the NVM Command Set Specification, with requirements for the Zone Append command defined in section 3.4.1.1.

2.1.6 Metadata Region (MR)

The Metadata Region is as defined in the NVM Command Set Specification.

2.2 I/O Controller Requirements

2.2.1 Command Support

This specification implements the command support requirements for I/O controllers defined in the NVM Express Base Specification and in the NVM Command Set Specification. Additionally, Figure 9 defines Zoned Namespace Command Set specific commands that are mandatory, optional, and prohibited for an I/O controller that supports the Zoned Namespace Command Set Specification.

Figure 9: I/O Controller – Zoned Namespace Command Set Support

Command	Combined Opcode Value	Controller Support Requirements ¹	Reference
Zone Management Send	79h	M	3.4.3
Zone Management Receive	7Ah	M	3.4.2
Zone Append	7Dh	O	3.4.1
Notes: O = Optional, M = Mandatory, P = Prohibited			

2.2.2 Log Page Support

This specification implements the log page support requirements for I/O controllers defined in the NVM Express Base Specification and in the NVM Command Set Specification. Additionally, Figure 10 defines Zoned Namespace Command Set specific log pages that are mandatory, optional, and prohibited for an I/O controller that supports the Zoned Namespace Command Set Specification.

Figure 10: I/O Controller - Zoned Namespace Command Set Specific Log Page Support

Log Page	Log Page Identifier	Log Page Support Requirements ¹	Reference
Changed Zone List	Bfh	O	4.1.4.1
Notes: O = Optional, M = Mandatory, P = Prohibited			

2.2.3 Features Support

This specification implements the feature support requirements for I/O controllers defined in the NVM Express Base Specification and in the NVM Command Set Specification. Additional requirements are defined in section 4.1.3.

3 I/O Commands for the Zoned Namespace Command Set

This section defines the Zoned Namespace Command Set I/O commands.

3.1 Submission Queue Entry and Completion Queue Entry

The submission queue entry (SQE) data structure and the completion queue entry (CQE) data structure are as defined in the NVM Command Set Specification, with changes as defined in this section.

3.1.1 Common Command Format

The Common Command Format is as defined in the NVM Express Base Specification.

3.1.2 Command Specific Status Values

This specification supports the Command Specific status values defined in the NVM Express Base Specification and in the NVM Command Set Specification. Command Specific status values that are specific to the Zoned Namespace Command Set Specification are defined in this section.

Figure 11 defines the status values specific to the Zoned Namespace Command Set.

Figure 11: Status Code – Command Specific Status Values, Zoned Namespace Command Set

Value	Definition	Commands Affected
B6h	Invalid Zone Operation Request	Zone Append, Zone Management Send
B7h	ZRWA Resources Unavailable	Zone Management Send
B8h	Zone Boundary Error	Compare ¹ , Copy ¹ , Read ¹ , Verify ¹ , Write, Write Uncorrectable, Write Zeroes, Zone Append
B9h	Zone Is Full	Copy, Write, Write Uncorrectable, Write Zeroes, Zone Append
BAh	Zone Is Read Only	Copy, Write, Write Uncorrectable, Write Zeroes, Zone Append, Zone Management Send
BBh	Zone Is Offline	Compare, Copy, Read, Verify, Write, Write Uncorrectable, Write Zeroes, Zone Append, Zone Management Send
BCh	Zone Invalid Write	Copy, Write, Write Uncorrectable, Write Zeroes
BDh	Too Many Active Zones	Copy, Write, Write Uncorrectable, Write Zeroes, Zone Append, Zone Management Send
BEh	Too Many Open Zones	Copy, Write, Write Uncorrectable, Write Zeroes, Zone Append, Zone Management Send
BFh	Invalid Zone State Transition	Zone Management Send

Notes:

1. This command is affected if the Read Across Zone Boundaries bit is cleared to '0' in the Zoned Namespace Command Set specific Identify Namespace data structure (refer to section 4.1.5.1).

3.2 Zoned Namespace Command Set Commands

This specification includes the commands listed in Figure 12. Section 3.3 describes the Zoned Namespace Command Set specific behavior for NVM Command Set I/O commands. Section 3.4 describes the commands defined by this specification. Commands are submitted as defined in the NVM Express Base Specification.

Figure 12: Opcodes for Zoned Namespace Command Set I/O Commands

Opcode by Field	Combined Function	Command ²	Reference
NVM Express Base Specification I/O commands implemented by this specification			
Refer to the NVM Express Base Specification		Flush	NVM Express Base Specification
Refer to the NVM Express Base Specification		Reservation Register	NVM Express Base Specification
Refer to the NVM Express Base Specification		Reservation Report	NVM Express Base Specification
Refer to the NVM Express Base Specification		Reservation Acquire	NVM Express Base Specification

Figure 12: Opcodes for Zoned Namespace Command Set I/O Commands

Opcode by Field		Combined Opcode ¹	Command ²	Reference
(07:02)	(01:00)			
Function	Data Transfer ³			
Refer to the NVM Express Base Specification		I/O Management Receive	NVM Express Base Specification	
Refer to the NVM Express Base Specification		Reservation Release	NVM Express Base Specification	
Refer to the NVM Express Base Specification		Cancel	NVM Express Base Specification	
Refer to the NVM Express Base Specification		I/O Management Send	NVM Express Base Specification	
NVM Command Set commands implemented by this specification				
Refer to the NVM Command Set Specification		Dataset Management	NVM Command Set Specification	
NVM Command Set commands modified by this specification				
Refer to the NVM Command Set Specification		Write	3.3.7	
Refer to the NVM Command Set Specification		Read	3.3.5	
Refer to the NVM Command Set Specification		Write Uncorrectable	3.3.8	
Refer to the NVM Command Set Specification		Compare	3.3.1	
Refer to the NVM Command Set Specification		Write Zeroes	3.3.9	
Refer to the NVM Command Set Specification		Verify	3.3.6	
Refer to the NVM Command Set Specification		Copy	3.3.2	
I/O commands defined in this specification				
0111 10b	01b	79h	Zone Management Send	3.4.3
0111 10b	10b	7Ah	Zone Management Receive	3.4.2
0111 11b	01b	7Dh	Zone Append	3.4.1

Notes:

1. Opcodes not listed are defined in the NVM Express Base Specification and in the NVM Command Set Specification.
2. All Zoned Namespace Command Set Commands use the Namespace Identifier (NSID) field. The value FFFFFFFFh is not supported in this field.
3. Indicates the data transfer direction of the command. All options to the command shall transfer data as specified or transfer no data. All commands, including vendor specific commands, shall follow this convention: 00b = no data transfer; 01b = host to controller; 10b = controller to host; 11b = bidirectional.

3.3 NVM Command Set I/O Commands

The Zoned Namespace Command Set section implements the NVM Command Set I/O commands, with changes as defined in this section.

3.3.1 Compare command

The Compare command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.1.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 13.

Figure 13: Compare – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.

3.3.2 Copy command

The Copy command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.2.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 14.

Figure 14: Copy – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies a Source Range Entry that contains logical blocks in more than one zone or a destination LBA range that contains logical blocks in more than one zone.
B9h	Zone Is Full: The zone specified by the destination LBA range is in the ZSF:Full state.
BAh	Zone Is Read Only: The zone specified by the destination LBA range is in the ZSRO:Read Only state.
BBh	Zone Is Offline: A zone specified by a Source Range Entry or the zone specified by the destination LBA range is in the ZSO:Offline state.
BCh	Zone Invalid Write: The write to the zone was not at the write pointer.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.

3.3.3 Dataset Management command

The Dataset Management command operates as defined in the NVM Command Set Specification, with the additional requirements defined in this section.

If the specified zone is in the ZSO:Offline state then the command shall be aborted with a status code of Zone is Offline.

3.3.3.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 15.

Figure 15: Dataset Management – Command Specific Status Values

Value	Definition
BBh	Zone Is Offline: A zone specified by a Source Range Entry or the zone specified by the destination LBA range is in the ZSO:Offline state.

3.3.4 Flush command

The Flush command operates as defined in the NVM Command Set Specification, with the additional requirements defined in this section.

If:

- a) a volatile write cache is present;
- b) a volatile write cache is enabled; and
- c) the specified zone is in the ZSO:Offline state,

then the command shall be aborted with a status code of Zone Is Offline.

3.3.4.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 16.

Figure 16: Flush – Command Specific Status Values

Value	Definition
BBh	Zone Is Offline: A zone specified by a Source Range Entry or the zone specified by the destination LBA range is in the ZSO:Offline state.

3.3.5 Read command

The Read command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.5.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 17.

Figure 17: Read – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.

3.3.6 Verify command

The Verify command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.6.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 18.

Figure 18: Verify – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.

3.3.7 Write command

The Write command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.7.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 19.

Figure 19: Write – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
B9h	Zone Is Full: The accessed zone is in the ZSF:Full state.
BAh	Zone Is Read Only: The accessed zone is in the ZSRO:Read Only state.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.
BCh	Zone Invalid Write: The write to a zone was not at the write pointer.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.

3.3.8 Write Uncorrectable command

The Write Uncorrectable command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.8.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 20.

Figure 20: Write Uncorrectable – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
B9h	Zone Is Full: The accessed zone is in the ZSF:Full state.
BAh	Zone Is Read Only: The accessed zone is in the ZSRO:Read Only state.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.
BCh	Zone Invalid Write: The write to a zone was not at the write pointer.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.

3.3.9 Write Zeroes command

The Write Zeroes command operates as defined in the NVM Command Set Specification, with the additional requirements associated with the zone type of the specified zones that the command operates on (refer to section 2.1.1.2).

3.3.9.1 Command Completion

Command completion is as defined in the NVM Command Set Specification, with the additional Zoned Namespace Command Set Command Specific status values that are defined in Figure 21.

Figure 21: Write Zeroes – Command Specific Status Values

Value	Definition
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
B9h	Zone Is Full: The accessed zone is in the ZSF:Full state.
BAh	Zone Is Read Only: The accessed zone is in the ZSRO:Read Only state.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.
BCh	Zone Invalid Write: The write to a zone was not at the write pointer.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.

3.4 Zoned Namespace Command Set I/O Commands

3.4.1 Zone Append command

The Zone Append command writes data and metadata, if applicable, to the I/O controller for the zone indicated by the ZSLBA field. The controller assigns the data and metadata, if applicable, to a set of logical blocks within the zone. The lowest LBA of the set of logical blocks written is returned in the completion queue entry (refer to section 3.4.1.2). The host may also specify protection information to include as part of the operation.

This command uses Command Dword 2, Command Dword 3, Command Dword 10, Command Dword 11, Command Dword 12, Command Dword 13, Command Dword 14, and Command Dword 15 fields. If the command uses PRPs for the data transfer, then the Metadata Pointer, PRP Entry 1, and PRP Entry 2 fields are used. If the command uses SGLs for the data transfer, then the Metadata SGL Segment Pointer and SGL Entry 1 fields are used. All other command specific fields are reserved.

Write ordering in the case of multiple outstanding Zone Append commands to a zone is undefined and left to the controller.

If the zone specified by the Zone Append command is not a Sequential Write Required zone, then the command shall be aborted with a status code of Invalid Field in Command.

If the ZSLBA field in the Zone Append command does not specify the lowest logical block for a zone, then the command shall be aborted with a status code of Invalid Field in Command.

If a Zone Append command is received for a zone while that zone is associated with a ZRWA, then the controller shall abort the command with a status code of Invalid Zone Operation Request.

The AWUN, NAWUN, NABSN, AWUPF, NAWUPF, NABSPF atomicity parameters apply as defined in the Atomic Operations section in the NVM Command Set Specification to the Zone Append command.

Figure 22: Zone Append – Metadata Pointer

Bits	Description
63:00	Metadata Pointer (MPTR): This field contains the Metadata Pointer, if applicable. Refer to the Common Command Format figure in the NVM Express Base Specification for the definition of this field.

Figure 23: Zone Append – Data Pointer

Bits	Description
127:00	Data Pointer (DPTR): This field specifies the location of a data buffer where data is transferred from. Refer to the Common Command Format figure in the NVM Express Base Specification for the definition of this field.

Figure 24: Zone Append – Command Dword 2 and Dword 3

Bits	Description
63:48	Reserved
47:00	Logical Block Tags Upper (LBTU): This field and Command Dword 14 specify the variable sized Logical Block Storage Tag (LBST) and Initial Logical Block Reference Tag (ILBRT) fields, which are defined in the NVM Express Base Specification. If the namespace is not formatted to use end-to-end protection information, then this field is ignored by the controller.

Figure 25: Zone Append – Command Dword 10 and Command Dword 11

Bits	Description
63:00	Zone Start Logical Block Address (ZSLBA): This field indicates the 64-bit address of the lowest logical block of the zone in which the data and metadata, if applicable, associated with this command is to be stored. Command Dword 10 contains bits 31:00; Command Dword 11 contains bits 63:32.

Figure 26: Zone Append – Command Dword 12

Bits	Description
31	Limited Retry (LR): If this bit is set to '1', then the controller should apply limited retry efforts. If this bit is cleared to '0', then the controller should apply all available error recovery means to write the data to the NVM, as defined in the NVM Command Set Specification.
30	Force Unit Access (FUA): If this bit is set to '1', then for data and metadata, if any, associated with logical blocks specified by the Zone Append command, the controller shall write that data and metadata, if any, to non-volatile medium before indicating command completion. There is no implied ordering with other commands. If this bit is cleared to '0', then this bit has no effect, as defined in the NVM Command Set Specification.
29:26	Protection Information (PRINFO): This field specifies the Protection Information field, as defined in the NVM Command Set Specification.
25	Protection Information Remap (PIREMAP): This bit determines the contents of the reference tag written to the media (refer to section 3.4.1.1). If this bit is cleared to '0' and the specified zoned namespace is formatted for Type 1 protection, the controller shall abort the command with a status of Invalid Protection Information. If this bit is set to '1' and the specified zoned namespace is formatted for Type 3 protection, the controller shall abort the command with a status of Invalid Protection Information.
24	Storage Tag Check (STC): This bit specifies that the Storage Tag field shall be checked as part of end-to-end data protection processing as defined in the NVM Command Set Specification.
23:20	Directive Type (DTYPE): Specifies the Directive Type associated with the Directive Specific field (refer to the NVM Express Base Specification).
19:16	Command Extension Type (CETYPE): Specifies the Command Extension Type that applies to the command (refer to the Key Per I/O section in the NVM Express Base Specification).
15:00	Number of Logical Blocks (NLB): This field indicates the number of logical blocks to be written. This is a 0's based value.

The definition of Command Dword 13 is based on the CETYPE value. If the CETYPE value is cleared to 0h, then Command Dword 13 is defined in Figure 27. If the CETYPE value is non-zero, then Command Dword 13 is defined in Figure 28.

Figure 27: Zone Append – Command Dword 13 if CETYPE is cleared to 0h

Bits	Description
31:16	Directive Specific (DSPEC) : Specifies the Directive Specific value associated with the Directive Type field (refer to the NVM Express Base Specification).
15:00	Reserved

Figure 28: Zone Append - Command Dword 13 if CETYPE is non-zero

Bits	Description
31:16	Directive Specific (DSPEC) : Specifies the Directive Specific value associated with the Directive Type field (refer to the Key Per I/O section in the NVM Express Base Specification).
15:00	Command Extension Value (CEV) : The definition of this field is dependent on the value of the CETYPE field. Refer to the Key Per I/O section in the NVM Express Base Specification.

Figure 29: Zone Append – Command Dword 14

Bits	Description
31:00	Logical Block Tags Lower (LBTL) : This field and bits 47:00 of Command Dword 2 and Dword 3 specify the variable sized Logical Block Storage Tag (LBST) and Initial Logical Block Reference Tag (ILBRT) fields, which are defined in the NVM Command Set Specification. If the namespace is not formatted to use end-to-end protection information, then this field is ignored.

Figure 30: Zone Append – Command Dword 15

Bits	Description
31:16	Logical Block Application Tag Mask (LBATM) : This field specifies the Application Tag Mask value. This field is ignored if the zoned namespace is not formatted to use end-to-end protection information. Refer to the End-to-end Data Protection section in the NVM Command Set Specification.
15:00	Logical Block Application Tag (LBAT) : This field specifies the Application Tag value. This field is ignored if the zoned namespace is not formatted to use end-to-end protection information. Refer to the End-to-end Data Protection section in the NVM Command Set Specification.

3.4.1.1 Protection Information

For the Zone Append command, the actual LBA where data is written by the command is not known to the host until the Zone Append command completes (refer to the ALBA field defined in section 3.4.1.2). The host is not able to provide the actual LBA of the data in the reference tags in the Protection Information at the time the Zone Append command is issued (refer to the End-to-end Data Protection section of the NVM Command Set Specification). As a result, handling of LBA based reference tags in the Protection Information is handled as defined in this section.

Unless otherwise specified, for the protection information received by the controller from the host, the checks performed by the controller shall be performed as defined in the Control of Protection Information Checking – PRCHK section of the NVM Command Set Specification.

For the Reference Tag written to the media, if the PIREMAP bit is:

- a) cleared to '0', then the controller shall write the Reference Tag to the media per the End-to-end Protection Information section of the NVM Command Set Specification without modification; or
- b) set to '1', then the controller shall write the Logical Block Reference Tag to media for the first and subsequent LBAs as follows:
 - A) Media Reference Tag[0] = ILBRT + (ALBA - ZSLBA); and
 - B) Media Reference Tag[n+1] = Media Reference Tag[n] + 1

Where: Media Reference Tag [0] is the Logical Block Reference Tag written to media for the first LBA, and Media Reference Tag [n+1] is the Logical Block Reference Tag written to media for all other LBAs.

If the specified zoned namespace is formatted for Type 1 protection and the PIREMAP bit is set to ‘1’, then the host should initialize the ILBRT field to the least-significant bits of the Zone Start Logical Block Address (ZSLBA) field sized to the number of bits in the Logical Block Reference Tag (refer to the Storage Tag and Logical Block Reference Tag from Storage and Reference Space section in the NVM Command Set Specification). If the value in the ILBRT field does not match the value in the ZSLBA field sized to the number of bits in the Logical Block Reference Tag, then the controller shall abort the command with a status code of Invalid Protection Information.

Note: When writing protection information using the Zone Append command with the PIREMAP bit set to ‘1’, the Logical Block Reference Tag written to media is not the value transferred from the host to the controller, but contains the value calculated as defined in this section.

The controller shall write all protection information received from the host, other than the Logical Block Reference Tag, to the media without modification.

3.4.1.2 Command Completion

When the command is completed, the controller shall post a completion queue entry (CQE) to the associated I/O Completion Queue indicating the status for the command. If the command is successfully completed, then the lowest LBA containing the data written by the command is returned in the Assigned LBA (ALBA) field of the completion queue entry. Dword 0 contains bits 31:00 of the ALBA field; Dword 1 contains bits 63:32 of the ALBA field. If the command is not successfully completed, then the contents of the ALBA field are undefined.

Figure 31 defines the Zone Append command specific status values.

Figure 31: Zone Append – Command Specific Status Values

Value	Definition
81h	Invalid Protection Information: The Protection Information (PRINFO) field settings specified in the command are invalid for the Protection Information with which the namespace was formatted or the ILBRT field is invalid (refer to section 3.4.1).
B6h	Invalid Zone Operation Request: The operation requested is invalid due to having received a Zone Append command for a zone associated with a ZRWA.
B8h	Zone Boundary Error: The command specifies logical blocks in more than one zone.
B9h	Zone Is Full: The accessed zone is in the ZSF:Full state.
BAh	Zone Is Read Only: The accessed zone is in the ZSRO:Read Only state.
BBh	Zone Is Offline: The accessed zone is in the ZSO:Offline state.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.

3.4.2 Zone Management Receive command

The Zone Management Receive command returns a data buffer that contains information about zones. That information includes characteristics of the zone, the state of the zone, the capacity of the zone, and other information defined in section 3.4.2.2. The host uses this command to determine the current settings for this information.

If this information changes (e.g., as indicated by the Capacity Changed bit set to ‘1’ in the completion queue entry of a Zone Management Send command, or by a Zone Descriptor Changed event), then the host may use this command to determine the current state of this information (e.g., the current capacity of the zone or the Reset Zone Recommended attribute).

The Zone Management Receive command uses the Data Pointer, Command Dword 10, Command Dword 11, Command Dword 12, and Command Dword 13 fields. All other command specific fields are reserved.

Figure 32: Zone Management Receive – Data Pointer

Bits	Description
127:00	Data Pointer (DPTR): This field specifies the location of a data buffer where data is transferred from. Refer to the NVM Express Base Specification for the definition of this field.

Figure 33: Zone Management Receive – Command Dword 10 and Command Dword 11

Bits	Description
63:00	Starting LBA (SLBA): This field specifies an LBA in the lowest numbered zone that the Zone Receive Action operates on. Command Dword 10 contains bits 31:00; Command Dword 11 contains bits 63:32.

Figure 34: Zone Management Receive – Command Dword 12

Bits	Description
31:00	Number of Dwords (NDW): This field specifies the number of dwords to return. If the host specifies a size larger than what the Zone Receive Action data structure returns, then the controller returns the complete result with undefined results for dwords beyond the end of the data of the Zone Receive Action data structure. This is a 0's based value.

Figure 35: Zone Management Receive – Command Dword 13

Bits	Description																																		
31:17	Reserved																																		
16	Zone Receive Action Specific Features (ZRASPF): <table border="1"> <thead> <tr> <th>Zone Receive Action</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>Report Zones</td> <td>Partial Report: If this bit is cleared to '0', then the value in the Number of Zones fields (refer to Figure 36 and Figure 37) indicates the number of Zone Descriptors that match the criteria in the Zone Receive Action Specific field.</td></tr> <tr> <td>Extended Report Zones</td> <td>If this bit is set to '1', then the value in the Number of Zones fields indicates the number of fully transferred Zone Descriptors in the data buffer.</td></tr> <tr> <td>All other values</td> <td>Reserved</td></tr> </tbody> </table>	Zone Receive Action	Definition	Report Zones	Partial Report: If this bit is cleared to '0', then the value in the Number of Zones fields (refer to Figure 36 and Figure 37) indicates the number of Zone Descriptors that match the criteria in the Zone Receive Action Specific field.	Extended Report Zones	If this bit is set to '1', then the value in the Number of Zones fields indicates the number of fully transferred Zone Descriptors in the data buffer.	All other values	Reserved																										
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Figure 35: Zone Management Receive – Command Dword 13

Bits	Description	
07:00	Zone Receive Action (ZRA):	
	Value	Definition
	00h	Report Zones: Reports Zone Descriptor entries through the Report Zones data structure (refer to Figure 36).
	01h	Extended Report Zones: Reports Zone Descriptor entries through the Extended Report Zones data structure (refer to Figure 37). This value is supported if the zoned namespace is formatted with a non-zero Zone Descriptor Extension Size. Otherwise, the controller shall abort the command with a status code of Invalid Field in Command.
02h to FFh	Reserved	

3.4.2.1 Zone Receive Actions

The Zone Management Receive command Zone Receive Action field specifies what action to perform.

3.4.2.1.1 Report Zones

The Report Zones action returns the Report Zones data structure (refer to Figure 36). The Zone Descriptors of the Report Zones data structure shall:

- a) report only Zone Descriptors of zones for which the ZSLBA value is greater than or equal to the ZSLBA value of the zone specified by the SLBA value in the command;
- b) match the criteria in the Zone Receive Action Specific field; and
- c) be sorted in ascending order by the ZSLBA value of each zone.

3.4.2.1.2 Extended Report Zones

The Extended Report Zones action returns the Extended Report Zones data structure (refer to Figure 37). The Zone Descriptors and Zone Descriptor Extensions of the Extended Report Zones data structure shall:

- a) report only Zone Descriptors and Zone Descriptor Extensions of zones for which the ZSLBA value of is greater than or equal to the ZSLBA value of the zone specified by the SLBA value in the command;
- b) match the criteria in the Zone Receive Action Specific field; and
- c) be sorted in ascending order by the ZSLBA value of each zone.

3.4.2.2 Zone Management Receive Data Structures

3.4.2.2.1 Report Zones Data Structure

Figure 36 defines the Report Zones Data Structure.

Figure 36: Report Zones Data Structure

Bytes	Description
07:00	Number of Zones (NZ): If the Partial Report bit (refer to Figure 35) is cleared to '0', then this field indicates the number of zones that match the criteria defined in section 3.4.2.1.1. If the Partial Report bit is set to '1', then this field indicates the number of zones for which complete Zone Descriptors were transferred to the data buffer. Refer to section 3.4.2.1.1 for the content of the data buffer.
63:08	Reserved
Zone Descriptor List	
127:64	Zone Descriptor 0: Contains the Zone Descriptor for the first zone reported, if any (refer to Figure 38).
191:128	Zone Descriptor 1: Contains the Zone Descriptor for the second zone reported, if any.
...	...
((NZ+1)*64)+63: (NZ+1)*64	Zone Descriptor NZ-1: Contains the Zone Descriptor for the last zone reported, if any.

3.4.2.2.2 Extended Report Zones Data Structure

Figure 37 defines the Extended Report Zones Data Structure.

Figure 37: Extended Report Zones Data Structure

Bytes ¹	Description
07:00	Number of Zones (NZ): If the Partial Report bit (refer to Figure 35) is cleared to '0', then this field indicates the number of zones that match the criteria defined in section 3.4.2.1.2. If the Partial Report bit is set to '1', then this field indicates the number of zones for which complete Zone Descriptors and complete Zone Descriptor Extensions were transferred to the data buffer. Refer to section 3.4.2.1.2 for the content of the data buffer.
63:08	Reserved
Zone Descriptor and Zone Descriptor Extension List	
127:64	Zone Descriptor 0: Contains the Zone Descriptor for the first zone reported, if any (refer to Figure 38).
(ZDES+127):128	Zone Descriptor Extension 0: Contains the Zone Descriptor Extension for the first zone reported, if any. If no Zone Descriptor Extension is associated with the zone, then the contents of this field are undefined.
(ZDES+191):(ZDES+128)	Zone Descriptor 1: Contains the Zone Descriptor for the second zone reported, if any.
((2*ZDES)+191):(ZDES+192)	Zone Descriptor Extension 1: Contains the Zone Descriptor Extension for the second zone reported, if any.
...	...
((NZ * ZDES)+((NZ + 1)*64) -1): (((NZ-1) * ZDES)+(NZ*64))	Zone Descriptor NZ-1: Contains the Zone Descriptor for the last zone reported, if any.
(((NZ)*ZDES)+((NZ +1) * 64) -1): (((NZ - 1) *ZDES)+((NZ + 1)*64))	Zone Descriptor Extension NZ-1: Contains the Zone Descriptor Extension for the last zone reported, if any.
Notes: 1. ZDES corresponds to the formatted Zone Descriptor Extension Size field in bytes (i.e. value multiplied by 64) (refer to Figure 50).	

3.4.2.2.3 Zone Descriptor Data Structure

Figure 38 defines the Zone Descriptor data structure.

Figure 38: Zone Descriptor Data Structure

Bytes	Description							
00	Zone Type Attributes (ZTATTR): This field indicates attributes for the type of the zone:							
	Bits	Description						
7:4	Reserved							
Zone Type (ZT): This field indicates the type of the zone.								
<table border="1"> <thead> <tr> <th>Value</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>2h</td> <td>Sequential Write Required</td> </tr> <tr> <td>All other values</td> <td>Reserved</td> </tr> </tbody> </table>		Value	Definition	2h	Sequential Write Required	All other values	Reserved	
Value	Definition							
2h	Sequential Write Required							
All other values	Reserved							

Figure 38: Zone Descriptor Data Structure

Bytes	Description																																																																																		
	Bits	Description																																																																																	
01	Zone State Attributes (ZSATTR): This field indicates attributes for the state of the zone:																																																																																		
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Figure 38: Zone Descriptor Data Structure

Bytes	Description
15:08	Zone Capacity (ZCAP): This field contains the maximum number of logical blocks that are available to be written with user data when the zone is in the ZSE:Empty state. This value shall be less than or equal to the Zone Size field (refer to Figure 50). If the Variable Zone Capacity bit is cleared to ‘0’ in the Zone Operation Characteristics field in the Zoned Namespace Command Set specific Identify Namespace data structure (refer to section 4.1.5.1), then this field does not change without a change to the format of the zoned namespace. If the Variable Zone Capacity bit is set to ‘1’ in the Zone Operation Characteristics field in the Zoned Namespace Command Set specific Identify Namespace data structure, then the zone capacity may change upon successful completion of a Zone Management Send command specifying the Zone Send Action of Reset Zone (refer to section 3.4.3.1.4.1).
23:16	Zone Start Logical Block Address (ZSLBA): This field contains the 64-bit address of the lowest logical block for the zone.
31:24	Write Pointer (WP): This field is the logical block address where the next write operation for this zone should be issued. Refer to section 2.1.1.2.1 for the behavior of the write pointer.
63:32	Reserved

3.4.2.3 Command Completion

When the command is completed, the controller shall post a completion queue entry (CQE) to the associated I/O Completion Queue indicating the status for the command.

3.4.3 Zone Management Send command

The Zone Management Send command requests an action on one or more zones. The command uses the Data Pointer, Command Dword 10, Command Dword 11, and Command Dword 13 fields. All other command specific fields are reserved.

Figure 39: Zone Management Send – Command Dword 10 and Command Dword 11

Bits	Description						
63:00	Starting LBA (SLBA): The definition of this field depends on the Zone Send Action, as shown in the following table: <table border="1"> <thead> <tr> <th>Zone Send Action</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>Flush Explicit ZRWA Range</td> <td>This field specifies the LBA of the highest-numbered logical block that is requested to be flushed. Command Dword 10 contains bits 31:00 of the SLBA; Command Dword 11 contains bits 63:32 of the SLBA (refer to section 3.4.3.1.3).</td> </tr> <tr> <td>All others</td> <td>This field specifies the LBA of the lowest-numbered logical block of the zone on which the Zone Send Action is performed. Command Dword 10 contains bits 31:00 of the SLBA; Command Dword 11 contains bits 63:32 of the SLBA.</td> </tr> </tbody> </table>	Zone Send Action	Definition	Flush Explicit ZRWA Range	This field specifies the LBA of the highest-numbered logical block that is requested to be flushed. Command Dword 10 contains bits 31:00 of the SLBA; Command Dword 11 contains bits 63:32 of the SLBA (refer to section 3.4.3.1.3).	All others	This field specifies the LBA of the lowest-numbered logical block of the zone on which the Zone Send Action is performed. Command Dword 10 contains bits 31:00 of the SLBA; Command Dword 11 contains bits 63:32 of the SLBA.
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All others	This field specifies the LBA of the lowest-numbered logical block of the zone on which the Zone Send Action is performed. Command Dword 10 contains bits 31:00 of the SLBA; Command Dword 11 contains bits 63:32 of the SLBA.						

Figure 40: Zone Management Send – Command Dword 13

Bits	Description
31:24	Reserved

Figure 40: Zone Management Send – Command Dword 13

Bits	Description																						
	Zone Management (ZM): This field indicates attributes for the Zone Send Action being issued.																						
	Zone Send Action	Definition																					
		<table border="1"> <thead> <tr> <th>Bits</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>07:06</td><td>Reserved</td></tr> <tr> <td>05:00</td><td> Data Lifetime (DL): The value in this field specifies an estimate of the relative Data Lifetime of this zone as compared to the relative Data Lifetime of other zones in this namespace. Refer to section 3.4.3.1.3. </td></tr> <tr> <td></td><td> <table border="1"> <thead> <tr> <th>Value</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>0h</td><td>No estimate is provided</td></tr> <tr> <td>1h</td><td>Shortest Data Lifetime</td></tr> <tr> <td>2h to 3Eh</td><td>Intermediate Data Lifetimes</td></tr> <tr> <td>3Fh</td><td>Longest Data Lifetime</td></tr> </tbody> </table> </td></tr> <tr> <td></td><td>All other values</td><td>Reserved</td></tr> </tbody> </table>	Bits	Description	07:06	Reserved	05:00	Data Lifetime (DL): The value in this field specifies an estimate of the relative Data Lifetime of this zone as compared to the relative Data Lifetime of other zones in this namespace. Refer to section 3.4.3.1.3.		<table border="1"> <thead> <tr> <th>Value</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>0h</td><td>No estimate is provided</td></tr> <tr> <td>1h</td><td>Shortest Data Lifetime</td></tr> <tr> <td>2h to 3Eh</td><td>Intermediate Data Lifetimes</td></tr> <tr> <td>3Fh</td><td>Longest Data Lifetime</td></tr> </tbody> </table>	Value	Definition	0h	No estimate is provided	1h	Shortest Data Lifetime	2h to 3Eh	Intermediate Data Lifetimes	3Fh	Longest Data Lifetime		All other values	Reserved
Bits	Description																						
07:06	Reserved																						
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2h to 3Eh	Intermediate Data Lifetimes																						
3Fh	Longest Data Lifetime																						
	All other values	Reserved																					
23:16	All other values Reserved																						
15:10	Reserved																						
09	Zone Send Action Specific Option (ZSASO):																						
	Zone Send Action	Definition																					
	Open Zone	ZRWA Allocation (ZRWAA): This bit controls the allocation of a Zone Random Write Area to a zone. Allocation of a ZRWA resource operates as described in section 3.4.3.1.4.1.																					
	Set Zone Descriptor Extension																						
	All others	Reserved																					
08	Select All (SELALL): If this bit is set to '1', then the SLBA field is ignored. If this bit is cleared to '0', then the SLBA field specifies the lowest logical block of the zone. Refer to section 3.4.3.1 for specific behavior for each Zone Send Action.																						
	Zone Send Action (ZSA): Defines the zone action to be performed for Zone Management Send.																						
	Value	Definition																					
	00h	Reserved																					
	01h	Close Zone: Close one or more zones.																					
	02h	Finish Zone: Finish one or more zones.																					
	03h	Open Zone: Open one or more zones.																					
	04h	Reset Zone: Reset one or more zones.																					
	05h	Offline Zone: Offline one or more zones.																					
	06h to 0Fh	Reserved																					
	10h	Set Zone Descriptor Extension: Attach Zone Descriptor Extension data to a zone.																					
	11h	Flush Explicit ZRWA Range: Flushes a range of logical blocks from a ZRWA to a zone.																					
	12h to FFh	Reserved																					

If the command completes successfully, depending on the Zone Send Action field and the current states of the zones specified by the command, then that command may affect zones in various ways, including the following:

- a) the zone state may change;
- b) the Zone Descriptor Extension data may change; and
- c) the Zone Descriptor Extension Valid bit in the Zone Attributes field may change.

If the controller has multiple outstanding Zone Management Send commands that specify one or more of the same zones, then the results are undefined.

If the zoned namespace containing the specified zone is write protected as described in the Namespace Write Protection section in the NVM Express Base Specification, then the controller shall abort the command with a status code of Namespace is Write Protected.

If there are insufficient available Active Resources, insufficient available Open Resources, or insufficient available ZRWA resources, then the command shall be aborted as defined in section 2.1.1.4, and no zone state transition shall occur.

If the command SLBA field does not specify the starting logical block for a zone in the specified zoned namespace, the Zone Send Action does not specify Flush Explicit ZRWA Range, and the Select All bit is cleared to '0', then the controller shall abort the command with a status code of Invalid Field in Command.

If the Zone Send Action field specifies the Set Zone Descriptor Extension Zone Send Action and the Zone Descriptor Extension Size field value in the Zoned Namespace Command Set specific Identify Namespace data structure is cleared to 0h, then the controller shall abort the command with a status code of Invalid Field in Command.

If the ZRWA Supported bit is cleared to '0' in the OZCS field, then the command shall be aborted with a status code of Invalid Zone Operation Request if the Zone Send Action field specifies:

- a) Open Zone with the ZRWAA bit set to '1';
- b) Set Zone Descriptor Extension with the ZRWAA bit set to '1'; or
- c) Flush Explicit ZRWA Range.

If the Zone Send Action field specifies Flush Explicit ZRWA Range and the EXPFLUSHSUP bit is cleared to '0' in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set, then the controller shall abort the command with a status code of Invalid Zone Operation Request.

For a shared zoned namespace, the method used by hosts to coordinate Zone Management Send commands is outside the scope of this specification.

3.4.3.1 Zone Send Actions

The Zone Management Send command Zone Send Action field defines what action to perform on one or more zones.

3.4.3.1.1 Close Zone

If the Select All bit in Command Dword 13 is cleared to '0', and the zone specified by the SLBA field is in the:

- a) ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state, then the zone shall be transitioned to the ZSC:Closed state;
- b) ZSC:Closed state, then no change shall be made to the zone state; and
- c) ZSE:Empty state, the ZSF:Full state, the ZSRO:Read Only state, or the ZSO:Offline state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the SLBA field shall be ignored and all zones that are in the:

- a) ZSIO:Implicitly Opened state; and
- b) ZSEO:Explicitly Opened state,

shall be transitioned to the ZSC:Closed state.

3.4.3.1.2 Finish Zone

If the Select All bit in Command Dword 13 is cleared to '0', and the zone specified by the SLBA field is in the:

- a) ZSE:Empty state, the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state, then the zone shall be transitioned to the ZSF:Full state;
- b) ZSF:Full state, then no change shall be made to the zone state; and
- c) ZSRO:Read Only state or the ZSO:Offline state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the SLBA field shall be ignored by the controller and all zones that are in the:

- a) ZSIO:Implicitly Opened state;

- b) ZSEO:Explicitly Opened state; and
- c) ZSC:Closed state,

shall be transitioned to the ZSF:Full state.

3.4.3.1.3 Flush Explicit ZRWA Range

The Zone Send Action of Flush Explicit ZRWA Range is a request to move data and metadata to the zone specified by the SLBA field. The logical blocks in the specified LBA range are written from the ZRWA associated with that zone to the zone.

The range of logical blocks to be flushed starts at the write pointer and ends at the LBA specified by the SLBA field in Command Dword 10 and Command Dword 11. On successful completion of a command for which the SLBA is not the highest-numbered LBA of the zone, the write pointer for that zone shall be set to one greater than the value in the SLBA field.

The number of logical blocks in the specified LBA range shall be a multiple of ZRWAFG. If the number of logical blocks to be flushed is not an integral multiple of ZRWAFG, then the controller shall abort the command with a status of Invalid Field in Command.

If the range of logical block addresses to be flushed by the Flush Explicit ZRWA Range Send Action contains a logical block address that is not contained in the ZRWA, then the command shall be aborted with a status code of Invalid Zone Operation Request.

Logical blocks which were not written to the ZRWA prior to being flushed by the Flush Explicit ZRWA Range Send Action shall be treated as unwritten logical blocks when read (refer to the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification).

If a Flush Explicit ZRWA Range Send Zone Action is requested and the specified zone is not:

- a) in the ZSEO:Explicitly Opened state, the ZSIO:Implicitly Opened state, or the ZSC:Closed state; and
- b) associated with a ZWRA,

then the controller shall abort the command with a status code of Invalid Zone Operation Request.

If the Select All bit is set to '1', the controller shall abort the command with a status code of Invalid Field in Command.

3.4.3.1.4 Open Zone

If the Select All bit is cleared to '0' in Command Dword 13 and the zone specified by the SLBA field is in the:

- a) ZSE:Empty state, the ZSIO:Implicitly Opened state or the ZSC:Closed state, then the zone should be transitioned to the ZSEO:Explicitly Opened state;
- b) ZSEO:Explicitly Opened state, then no change shall be made to the zone state; and
- c) ZSF:Full state, the ZSRO:Read Only state, or the ZSO:Offline state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the SLBA field shall be ignored and all zones that are in the ZSC:Closed state should be transitioned to the ZSEO:Explicitly Opened state.

If there are insufficient available Active Resources or insufficient available Open Resources, then the command shall be aborted as described in section 2.1.1.4 and no zone state transition shall occur.

The Data Lifetime of a zone is relative to the Data Lifetimes of other zones in the same namespace.

The Data Lifetime of a zone is not defined until a Zone Management Send command is processed that transitions that zone from the ZSE:Empty state to the ZSEO:Explicitly Opened state or the ZSC:Closed state.

The Data Lifetime of a zone (refer to Figure 40) represents the expected time from a Zone Management Send command transitioning that zone from the ZSE:Empty state to the ZSEO:Explicitly Opened state or the ZSC:Closed state (refer to section 2.1.1.4) until that zone transitions to:

- a) the ZSE:Empty state; or
- b) the ZSO:Offline state.

3.4.3.1.4.1 Open Zone ZRWA Allocation

The Zone Random Write Area Allocation (ZRWAA) bit in the Zone Send Action Specific Features field controls the allocation of a ZRWA to a zone in a Zone Management Send command when the Zone Send Action is set to Open Zone or set to Set Zone Descriptor Extension.

If the ZRWAA bit is cleared to '0' or a ZRWA is associated with this zone, then the processing of the command shall have no effect on ZRWA resources.

If the ZRWAA bit is set to '1' and there is no ZRWA associated with the zone, then:

- if no ZRWA resources are available, then the controller shall abort the command with a status code of ZRWA Resources Unavailable and no zone state transition shall occur; and
- if the zone is not in the ZSE:Empty state, then the controller shall abort the command with a status code of Invalid Zone Operation Request and no zone state transition shall occur.

A ZRWA shall be allocated to the specified zone upon successful completion of the Zone Management Send command if:

- the ZRWAA bit is set to '1';
- a ZRWA resource is available (refer to Number of ZRWA Resources field and section 2.1.1.4.1);
- no ZRWA is currently associated with the specified zone;
- the Zone Send Action is set to Open Zone or set to Set Zone Descriptor Extension; and
- the zone is in the ZSE:Empty state.

3.4.3.1.5 Reset Zone

If the Select All bit in Command Dword 13 is cleared to '0', and the zone specified by the SLBA field is in the:

- a) ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, the ZSC:Closed state, or the ZSF:Full state, then the specified zone shall be transitioned to the ZSE:Empty state;
- b) ZSE:Empty state, then no change shall be made to the zone state; and
- c) ZSRO:Read Only state, or the ZSO:Offline state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the SLBA field shall be ignored and all zones that are in the:

- a) ZSIO:Implicitly Opened state;
- b) ZSEO:Explicitly Opened state;
- c) ZSC:Closed state; and
- d) the ZSF:Full state,

shall be transitioned to the ZSE:Empty state.

If the command completes successfully, then for each affected zone:

- a) the Write Pointer field in the Zone Attributes field in the Zone Descriptor shall be set to the ZSLBA of the zone; and
- b) the following bits in the Zone Attributes field in the Zone Descriptor shall be cleared to '0':
 - a) Zone Descriptor Extension Valid;
 - b) Finish Zone Recommended;
 - c) Reset Zone Recommended;
 - d) Zone Finished by Controller; and
 - e) Zone Random Write Area Valid.

If the Variable Zone Capacity bit is set to '1' in the Zone Operation Characteristics field in the Zoned Namespace Command Set specific Identify Namespace data structure (refer to Figure 49), then the controller may change the Zone Capacity field in the Zone Descriptor of each affected zone. If the Zone Capacity field is changed for one or more zones, then the Zone Capacity Changed bit shall be set to '1' in the completion queue entry Dword 0 (refer to section 3.4.3.2).

3.4.3.1.6 Offline Zone

If the Select All bit in Command Dword 13 is cleared to '0', and the zone specified by the SLBA field is in the:

- a) ZSRO:Read Only state, then the specified zone shall be transitioned to the ZSO:Offline state;
- b) ZSO:Offline state, then no change shall be made to the zone state; and
- c) ZSE:Empty state, the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, the ZSC:Closed state, or the ZSF:Full state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the SLBA field shall be ignored, and all zones that are in the ZSRO:Read Only state shall be transitioned to the ZSO:Offline state.

3.4.3.1.7 Set Zone Descriptor Extension

If the Select All bit in Command Dword 13 is cleared to '0' and the zone specified by the SLBA field is in:

- a) the ZSE:Empty state, then the zone shall be transitioned to the ZSC:Closed state; and
- b) any state other than the ZSE:Empty state, then the controller shall abort the command with a status code of Invalid Zone State Transition.

If the Select All bit is set to '1', then the command shall be aborted with a status code of Invalid Field in Command.

If there are insufficient available Active Resources, the command shall be aborted as described in section 2.1.1.4 and no zone state transition shall occur.

On successful command completion, the Zone Descriptor Extension of the zone shall be set to the data in the data buffer.

3.4.3.2 Command Completion

When the command is completed, the controller shall post a completion queue entry (CQE) to the associated I/O Completion Queue indicating the status for the command. Figure 41 defines the Zone Management Send command specific status values.

Figure 41: Zone Management Send – Command Specific Status Values

Value	Definition
B6h	Invalid Zone Operation Request: The operation requested is invalid. This may be due to various conditions, including: <ul style="list-style-type: none"> • attempting to allocate a ZRWA when a zone is not in the ZSE:Empty state; or • invalid Flush Explicit ZRWA Range Send Zone Action operation.
B7h	ZRWA Resources Unavailable: No ZRWAs are available.
BAh	Zone Is Read Only: Zone is in the ZSRO:Read Only state. This may have occurred during the processing of the command.
BBh	Zone Is Offline: Zone is in the ZSO:Offline state. This may have occurred during the processing of the command.
BDh	Too Many Active Zones: The controller does not allow additional active zones.
BEh	Too Many Open Zones: The controller does not allow additional open zones.
BFh	Invalid Zone State Transition: The request is not a valid zone state transition.

Dword 0 of the completion queue entry indicates if the zone capacity of the specified zone has been changed. The definition of Dword 0 of the completion queue entry is in Figure 42.

Figure 42: Zone Management Send – Completion Queue Entry Dword 0

Bits	Description
31:01	Reserved
00	Zone Capacity Changed (ZCC): This bit indicates if the zone capacity has changed for one or more of the zones specified by the command. If this bit is set to '1', then a zone capacity has changed due to this command. If this bit is cleared to '0', then a zone capacity has not changed due to this command.

If a zone capacity change occurred, then the host may use the Zone Management Receive command as defined in section 3.4.1 to determine what has changed.

4 Admin Commands for the Zoned Namespace Command Set

4.1 Admin Command behavior for the Zoned Namespace Command Set

The Admin commands are as defined in the NVM Express Base Specification. The Zoned Namespace Command Set specific behavior for Admin commands is defined in this section.

4.1.1 Asynchronous Event Request Command

The Asynchronous Event Request command operates as defined in the NVM Express Base Specification. In addition to the Asynchronous Events defined in the NVM Express Base Specification and in the NVM Command Set Specification, the Zoned Namespace Command Set defines the Asynchronous Events in this section.

Figure 43 defines the Zoned Namespace Command Set specific Asynchronous Event Information – Notice data structure.

Figure 43: Asynchronous Event Information – Notice, Zoned Namespace Command Set

Value	Definition
EFh	<p>Zone Descriptor Changed: The Zone Descriptor data structure for a zone in a specific zoned namespace (refer to Figure 44) has changed. The Zone Descriptor of the zone that changed is indicated in the Changed Zone List log page. To clear this event, the host reads the Zone Changed List log page using the Get Log Page command with the Retain Asynchronous Event bit cleared to ‘0’.</p> <p>For a specific zone, a Zone Descriptor data structure change that occurred, for any of the following reasons shall not generate a Zone Descriptor Changed event and shall not cause modifications to the Changed Zones List log page:</p> <ul style="list-style-type: none"> a) a Zone Management Send command that specified that zone; b) a Zone Management Send command that specified all zones; c) a write operation that transitioned that zone: <ul style="list-style-type: none"> i. from the ZSE:Empty state to the ZSIO:Implicitly Opened state; ii. from the ZSIO:Implicitly Opened state to the ZSF:Full state; iii. from the ZSEO:Explicitly Opened state to the ZSF:Full state; or iv. from the ZSC:Closed state to the ZSIO:Implicitly Opened state; d) the controller transitioning that zone to the ZSF:Full state due to an NVM Subsystem Reset; and e) the controller transitioning that zone to the ZSC:Closed state (refer to section 2.1.1.4.1).

4.1.1.1 Command Completion

A completion queue entry (CQE) is posted to the Admin Completion Queue if there is an asynchronous event to report to the host. A controller implements the same logic defined for the Asynchronous Event Request command in the NVM Express Base Specification, with the following addition:

Figure 44: Asynchronous Event Request – Completion Queue Entry Dword 1

Bytes	Description
3:0	<p>Namespace Identifier (NSID): If the Asynchronous Event Request command returned a Zoned Namespace Command Set Notice event (refer to Figure 43), then this field indicates the namespace identifier that the asynchronous event occurred on. If the Asynchronous Event Request command returned an event other than a Zoned Namespace Command Set Notice event, then this field is reserved.</p> <p>If the Asynchronous Event Request command did not complete successfully, then this field is reserved.</p>

4.1.2 Format NVM command

The Format NVM command operates as defined in the NVM Express Base Specification and in the NVM Command Set Specification. The Format Index indicates:

- a) a valid User Data Format from the LBA Format field in the NVM Command Set Identify Namespace data structure;

- b) a valid Extended LBA Format in the I/O Command Set specific Identify Namespace data structure for the NVM Command Set; and
- c) a valid LBA Format Extension in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set.

4.1.3 Get Features and Set Features Commands

Features support requirements for I/O controllers supporting the Zoned Namespace Command Set are as defined in the NVM Command Set Specification and in this section.

Figure 45 defines the Zoned Namespace Command Set specific Set Features Command Asynchronous Event Configuration – Command Dword 11 data structure (refer to the NVM Express Base Specification).

Figure 45: Asynchronous Event Configuration – Command Dword 11

Bits	Description
27	Zone Descriptor Changed Notices (ZDCN): This bit specifies whether an asynchronous event notification is sent to the host for a Zone Descriptor Changed event. If this bit is set to '1', then the Zone Descriptor Changed event is sent as defined in Figure 43 when this condition occurs. If this bit is cleared to '0', then the controller shall not send the Zone Descriptor Changed event to the host.

4.1.4 Get Log Page Command

The Get Log Page command operates as defined in the NVM Express Base Specification and in the NVM Command Set Specification.

In addition to the log pages defined in the NVM Express Base Specification and in the NVM Command Set Specification, the Zoned Namespace Command Set defines the log pages in this section.

Log page scope is as defined in the NVM Express Base Specification, except as modified by this specification.

The rules for namespace identifier usage are defined in the NVM Express Base Specification.

Figure 46: Log Page Identifiers

Log Page Identifier	CSI ²	Scope	Log Page Name	Reference
BFh	Y	Namespace ¹	Changed Zone List	4.1.4.1
Key: Namespace = The log page contains information about a specific zoned namespace.				
Notes: 1. For namespace identifiers other than 0h or FFFFFFFFh. 2. If multiple I/O Command Sets are supported (refer to the NVM Express Base Specification), then the CSI field is used by the log page: Y = Yes, N = No. If Yes, refer to the definition of the log page for details on usage.				

4.1.4.1 Changed Zone List (Log Page Identifier BFh)

This log page indicates if a Zone Descriptor Changed event has occurred for one or more zones. If there is an enabled Zone Descriptor Changed Event pending for a specific zone, then the Changed Zone List includes an entry for that zone.

The Changed Zone List log page is 4,096 bytes in size. This log page contains a Zone Identifier List with up to 511 Zone Identifier entries. The Changed Zone List log page is defined in Figure 47.

A Zone Identifier entry contains the ZSLBA of the zone associated with the changed Zone Descriptor. Each ZSLBA shall appear not more than once in the Zone Identifier List. Unused entries shall be zero-filled.

Figure 47: Changed Zone List Log Page

Bytes	Description
Header	
01:00	Number of Zone Identifiers (NZID): This field indicates the number of Zone Identifiers entries in the list.
07:02	Reserved
Zone Identifier List	
15:08	Zone Identifier 0: This field contains the ZSLBA of the first zone in the list, if present.
23:16	Zone Identifier 1: This field contains the ZSLBA of the second zone in the list, if present.
...	...
((NZID-1)*8+15): ((NZID-1)*8+8)	Zone Identifier NZID-1: This field contains the ZSLBA of the last zone in the list, if present.

The controller shall set the Number of Zone Identifiers field in the log page to the number of valid entries contained in the Zone Identifier List data structure.

To determine changes, the host reads the Changed Zone List log page, and for each ZSLBA specified in a Zone Identifier entry, issues a Zone Management Receive command with the Zone Receive Action set to Report Zones or Extended Report Zones, and specifying the ZSLBA from that Zone Identifier entry.

The host should read the entire page with the RAE bit cleared to '0'. This log page is dynamic and when reading with offset without the header then the data may be changed from a previous read of the page.

For a given zoned namespace, if the controller is unable to populate the Changed Zone List log page with any valid entries and there is at least one Zone Descriptor Changed event since the last time the log page was read, then the controller shall set the Number of Zone Identifiers in that log page to FFFFh, and the remainder of the list shall be zero filled. The host may read the entire Report Zones data structure or the entire Extended Report Zones data structure to discover which Zone Descriptors have changed since the last time the information was read.

The log page content should not be retained after an NVM Subsystem Reset.

4.1.5 Identify Command

This specification implements the Identify Command and associated Identify data structures defined in the NVM Express Base Specification and in the NVM Command Set Specification. Additionally, the Zoned Namespace Command Set defines the Identify data structures defined in this section.

Each I/O Command Set is assigned a specific Command Set Identifier (CSI) value by the NVM Express Base Specification. The Zoned Namespace Command Set is assigned a CSI value of 02h.

Figure 48: CNS Values

CNS Value	O/M¹	Definition	NSID²	CNTID³	CSI⁴	Reference Section
Active Namespace Management						
00h	M	Identify Namespace data structure for the specified NSID or the namespace capabilities for the NVM Command Set. ⁵	Y	N	N ⁶	NVM Command Set Specification
01h	M	Identify Controller Data Structure, I/O Command Set Independent. ⁵	N	N	N	NVM Express Base Specification
05h	M	I/O Command Set specific Identify Namespace data structure for the specified NSID for the I/O Command Set specified in the CSI field. ⁵	Y	N	00h	NVM Command Set Specification
					02h	4.1.5.1

Figure 48: CNS Values

CNS Value	O/M ¹	Definition	NSID ²	CNTID ³	CSI ⁴	Reference Section
06h	M	I/O Command Set specific Identify Controller data structure for the controller processing the command. ⁵	N	N	00h	NVM Command Set Specification
					02h	4.1.5.2
09h	O	Identify Namespace data structure for the specified Format Index containing the namespace capabilities for the NVM Command Set. ⁵	N	N	00h	NVM Command Set Specification
0Ah	O	I/O Command Set specific Identify Namespace data structure for the specified Format Index for the I/O Command Set specified in the CSI field. ⁵	N	N	00h	NVM Command Set Specification
					02h	0
11h	O	Identify Namespace data structure for the specified allocated NSID.	Y	N	N	NVM Command Set Specification
16h	O	A Namespace Granularity List is returned to the host.	N	N	Y	NVM Command Set Specification

Notes:

1. O/M definition: O = Optional, M = Mandatory.
2. The NSID field is used: Y = Yes, N = No.
3. The CDW10.CNTID field is used: Y = Yes, N = No.
4. The CDW11.CSI field value or N if the field is not used. Since this specification is an extension of the NVM Command Set (refer to section 1.1) a host is required to use the CSI value of 00h and the CSI value of 02h to obtain all of the refer to section 1.4.2.3, section 1.4.2.4, and section 4.1.5.4.
5. Selection of a UUID may be supported. Refer to the UUIDs for Vendor Specific Information section of the NVM Command Set Specification.
6. This Identify data structure applies to namespaces that are associated with command sets that specify logical blocks (i.e., Command Set Identifier 0h or Command Set Identifier 02h).

4.1.5.1 I/O Command Set Specific Identify Namespace Data Structure for the Zoned Namespace Command Set (CNS 05h, CSI 02h)

Figure 49 defines the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set.

Figure 49 specifies fields in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set that define capabilities used by a host to format or create a namespace. If the NSID field is set to FFFFFFFFh, then the controller shall return an I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set that:

- for fields in Figure 49 that indicate “Yes” in the Reported column, contain a value that is the same for all namespaces using any of the LBA formats associated with the Number of LBA Formats field (refer to the LBA Format List Structure section in the NVM Command Set Specification); and
- for fields in Figure 49 that indicate “No” in the Reported column, contain a value cleared to 0h.

If the controller supports the Namespace Management capability (refer to the Namespace Management section in the NVM Express Base Specification) and the NSID field is set to FFFFFFFFh, then the controller shall return an I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set. If the controller does not support the Namespace Management capability and the NSID field is set to FFFFFFFFh, then the controller may abort the command with a status code of Invalid Namespace or Format.

Figure 49: I/O Command Set Specific Identify Namespace Data Structure for the Zoned Namespace Command Set

Bytes	O/M ¹	Description	Reported ²								
01:00	O	<p>Zone Operation Characteristics (ZOC): This field indicates the zone operation characteristics of the zoned namespace.</p> <table border="1"> <thead> <tr> <th>Bits</th><th>Description</th></tr> </thead> <tbody> <tr> <td>15:2</td><td>Reserved</td></tr> <tr> <td>1</td><td>Zone Active Excursions (ZAE): If this bit is set to '1', then a controller may transition a zone in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state to the ZSF:Full state due to a vendor specific excursion event. If this bit is cleared to '0', then a controller shall not transition a zone due to a vendor specific excursion event. Refer to section 5.6.</td></tr> <tr> <td>0</td><td>Variable Zone Capacity (VZC): if this bit is set to '1', then the capacity for a zone may change without a change to the format of the zoned namespace. If this bit is cleared to '0', then the capacity for a zone does not change without a change to the format of the zoned namespace. Refer to Figure 38.</td></tr> </tbody> </table>	Bits	Description	15:2	Reserved	1	Zone Active Excursions (ZAE): If this bit is set to '1', then a controller may transition a zone in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state to the ZSF:Full state due to a vendor specific excursion event. If this bit is cleared to '0', then a controller shall not transition a zone due to a vendor specific excursion event. Refer to section 5.6.	0	Variable Zone Capacity (VZC): if this bit is set to '1', then the capacity for a zone may change without a change to the format of the zoned namespace. If this bit is cleared to '0', then the capacity for a zone does not change without a change to the format of the zoned namespace. Refer to Figure 38.	No
Bits	Description										
15:2	Reserved										
1	Zone Active Excursions (ZAE): If this bit is set to '1', then a controller may transition a zone in the ZSIO:Implicitly Opened state, the ZSEO:Explicitly Opened state, or the ZSC:Closed state to the ZSF:Full state due to a vendor specific excursion event. If this bit is cleared to '0', then a controller shall not transition a zone due to a vendor specific excursion event. Refer to section 5.6.										
0	Variable Zone Capacity (VZC): if this bit is set to '1', then the capacity for a zone may change without a change to the format of the zoned namespace. If this bit is cleared to '0', then the capacity for a zone does not change without a change to the format of the zoned namespace. Refer to Figure 38.										
03:02	O	<p>Optional Zoned Command Support (OZCS): This field defines optional features of the zoned namespace.</p> <table border="1"> <thead> <tr> <th>Bits</th><th>Description</th></tr> </thead> <tbody> <tr> <td>15:2</td><td>Reserved</td></tr> <tr> <td>1</td><td>ZRWA Supported (ZRWASUP): If this bit is set to '1' then the namespace supports the ZRWA capability. If this bit is cleared to '0', then the namespace does not support the ZRWA capability. Refer to section 5.7.</td></tr> <tr> <td>0</td><td>Read Across Zone Boundaries (RAZB): If this bit is set to '1', then any User Data Read Access Command is allowed to perform read operations that specify an LBA range containing logical blocks in more than one zone. If this bit is cleared to '0', then any command that performs a read operation that specifies an LBA range containing logical blocks in more than one zone is aborted as defined in section 2.1.1.2.1.2.</td></tr> </tbody> </table>	Bits	Description	15:2	Reserved	1	ZRWA Supported (ZRWASUP): If this bit is set to '1' then the namespace supports the ZRWA capability. If this bit is cleared to '0', then the namespace does not support the ZRWA capability. Refer to section 5.7.	0	Read Across Zone Boundaries (RAZB): If this bit is set to '1', then any User Data Read Access Command is allowed to perform read operations that specify an LBA range containing logical blocks in more than one zone. If this bit is cleared to '0', then any command that performs a read operation that specifies an LBA range containing logical blocks in more than one zone is aborted as defined in section 2.1.1.2.1.2.	No
Bits	Description										
15:2	Reserved										
1	ZRWA Supported (ZRWASUP): If this bit is set to '1' then the namespace supports the ZRWA capability. If this bit is cleared to '0', then the namespace does not support the ZRWA capability. Refer to section 5.7.										
0	Read Across Zone Boundaries (RAZB): If this bit is set to '1', then any User Data Read Access Command is allowed to perform read operations that specify an LBA range containing logical blocks in more than one zone. If this bit is cleared to '0', then any command that performs a read operation that specifies an LBA range containing logical blocks in more than one zone is aborted as defined in section 2.1.1.2.1.2.										
07:04	M	Maximum Active Resources (MAR): This field defines the maximum number of active zones in the zoned namespace. A value of FFFFFFFFh indicates that there is no limit. This is a 0's based value	No								
11:08	M	Maximum Open Resources (MOR): This field defines the maximum number of open zones in the zoned namespace. This field shall be less than or equal to the Maximum Active Resources field. A value of FFFFFFFFh indicates that there is no limit. This is a 0's based value	No								
15:12	O	Reset Recommended Limit (RRL): If the Reset Zone Recommended Time Limit field is cleared to 00b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform a vendor specific action on a zone after the Reset Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.4.	No								
19:16	O	Finish Recommended Limit (FRL): If the Finish Zone Recommended Time Limit field is cleared to 00b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform the vendor specific action on a zone after the Finish Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.5.	No								
23:20	O	Reset Recommended Limit 1 (RRL1): If the Reset Zone Recommended Time Limit field is set to 01b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform a vendor specific action on a zone after the Reset Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.4.	No								

Figure 49: I/O Command Set Specific Identify Namespace Data Structure for the Zoned Namespace Command Set

Bytes	O/M ¹	Description	Reported ²						
27:24	O	Reset Recommended Limit 2 (RRL2): If the Reset Zone Recommended Time Limit field is set to 10b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform a vendor specific action on a zone after the Reset Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.4.	No						
31:28	O	Reset Recommended Limit 3 (RRL3): If the Reset Zone Recommended Time Limit field is set to 11b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform a vendor specific action on a zone after the Reset Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.4.	No						
35:32	O	Finish Recommended Limit 1 (FRL1): If the Finish Zone Recommended Time Limit field is set to 01b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform the vendor specific action on a zone after the Finish Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.5.	No						
39:36	O	Finish Recommended Limit 2 (FRL2): If the Finish Zone Recommended Time Limit field is set to 10b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform the vendor specific action on a zone after the Finish Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.5.	No						
43:40	O	Finish Recommended Limit 3 (FRL3): If the Finish Zone Recommended Time Limit field is set to 11b in the Zone Attributes Information field, then this field indicates the number of seconds before the NVM subsystem may perform the vendor specific action on a zone after the Finish Zone Recommended bit is set to '1' in the Zone Attributes field for that zone. If this field is cleared to 0h, then no limit is reported. Refer to section 5.5.	No						
47:44	O	Number of ZRWA Resources (NUMZRWA): This field indicates the total number of ZRWA resources in this namespace. Refer to section 5.7. This field is a 0's based value. If the ZRWA Supported bit is cleared to '0' in the OZCS field, then this field shall be ignored.	No						
49:48	O	ZRWA Flush Granularity (ZRWAFG): This field specifies the granularity of ZRWA Flush operations (refer to section 5.7.1) in logical blocks for this namespace. Unless otherwise specified, data shall be flushed from logical blocks in a ZRWA to its associated zone in integral multiples of the value in this field. If the ZRWA Supported bit is cleared to '0' in the OZCS field, then this field shall be cleared to 0h. This value may change if the namespace is reformatted.	No						
51:50	O	ZRWA Size (ZRWASZ): This field indicates the total size in logical blocks of each ZRWA for this namespace. The value in this field shall be a multiple of the non-zero value of the ZRWA Flush Granularity (ZRWAFG) field. If the ZRWA Supported bit is cleared to '0' in the OZCS field, then this field shall be cleared to 0h. Refer to section 5.7. This value may change if the namespace is reformatted.	No						
52	O	ZRWA Capability (ZRWACAP): This field provides information about the ZRWA capability. If the ZRWA Supported bit is cleared to '0' in the OZCS field, then this field shall be cleared to 0h. <table border="1" style="margin-top: 5px;"> <thead> <tr> <th>Bits</th><th>Description</th></tr> </thead> <tbody> <tr> <td>7:1</td><td>Reserved</td></tr> <tr> <td>0</td><td>Explicit Flush Support (EXPFLUSHSUP): If this bit is set to '1', then the controller supports explicit ZRWA Flush operations (refer to section 5.7.2). If this bit is cleared to '0', then the controller does not support explicit ZRWA Flush operations.</td></tr> </tbody> </table>	Bits	Description	7:1	Reserved	0	Explicit Flush Support (EXPFLUSHSUP): If this bit is set to '1', then the controller supports explicit ZRWA Flush operations (refer to section 5.7.2). If this bit is cleared to '0', then the controller does not support explicit ZRWA Flush operations.	No
Bits	Description								
7:1	Reserved								
0	Explicit Flush Support (EXPFLUSHSUP): If this bit is set to '1', then the controller supports explicit ZRWA Flush operations (refer to section 5.7.2). If this bit is cleared to '0', then the controller does not support explicit ZRWA Flush operations.								
2815:53		Reserved							

Figure 49: I/O Command Set Specific Identify Namespace Data Structure for the Zoned Namespace Command Set

Bytes	O/M ¹	Description	Reported ²
LBA Format Extensions (refer to the LBA Format List Structure section in the NVM Command Set Specification)			
2831:2816	M	LBA Format 0 Extension (LBAFE0): This field indicates the LBA format Extension 0 that is supported by the controller. The LBA Format Extension field is defined in Figure 50.	Yes
2847:2832	O	LBA Format 1 Extension (LBAFE1): This field indicates the LBA format Extension 1 that is supported by the controller. The LBA Format Extension field is defined in Figure 50.	Yes
...			
3839:3824	O	LBA Format 63 Extension (LBAFE63): This field indicates the LBA format Extension 63 that is supported by the controller. The LBA Format Extension field is defined in Figure 50.	Yes
4095:3840	O	Vendor Specific (VS)	No
Notes:			
1. O/M definition: O = Optional, M = Mandatory.			
2. Identifies fields that report information for the Identify command when querying the capabilities of LBA formats.			

Figure 50 defines the Identify LBA Format Extension data structure.

Figure 50: LBA Format Extension Data Structure

Bits	Description
127:72	Reserved
71:64	Zone Descriptor Extension Size (ZDES): This field indicates the Zone Descriptor Extension size for each zone. The value is reported in 64B units (e.g., 1h corresponds to 64B, 2h corresponds to 128B). A value of 0h indicates that Zone Descriptor Extensions are not supported. Refer to section 5.3.
63:00	Zone Size (ZSZE): This field contains the size of each zone in the zoned namespace. The value is reported as a number of logical blocks. The value of the field shall not be cleared to 0h.

The LBA Format data structure in the NVM Command Set specific Identify Namespace data structure is as defined in the NVM Command Set Specification. That LBA Format data structure is extended through the LBA Format Extension data structure.

Commands (e.g., Format NVM and Namespace Management) that use the Format Index to refer to the LBA Format data structure in the NVM Command Set specific Identify Namespace data structure, shall use that same Format Index to refer to the LBA Format Extension data structure and shall process both the LBA Format data structure and LBA Format Extension data structure when an LBA Format is specified.

The host specified namespace management fields are as defined for the NVM Command Set.

4.1.5.2 I/O Command Set Specific Identify Controller Data Structure (CNS 06h, CSI 02h)

Figure 51 defines the I/O Command Set specific Identify Controller data structure for the Zoned Namespace Command Set.

Figure 51: I/O Command Set Specific Identify Controller Data Structure for the Zoned Namespace Command Set

Bytes	O/M ¹	Description						
00	O ²	<p>Zone Append Size Limit (ZASL): If the Zone Append command is supported then:</p> <ul style="list-style-type: none"> a) a non-zero value in this field indicates the maximum data transfer size for the Zone Append command (refer to section 3.4.1); and b) a value of 0h in this field indicates that the maximum data transfer size for the Zone Append command is indicated by the Maximum Data Transfer Size (MDTS) field (refer to the NVM Express Base Specification). <p>The value is in units of the minimum memory page size (CAP.MPSMIN) and is reported as a power of two (2^n). This field includes the length of metadata if metadata is interleaved with the stored logical block data.</p> <p>The value of this field shall be less than or equal to the Maximum Data Transfer Size (MDTS).</p>						
03:01		Reserved						
07:04	O ³	<p>Zoned Controller Attributes (ZCTRATT): This field indicates attributes of the controller that support this command set.</p> <table border="1"> <thead> <tr> <th>Bits</th><th>Description</th></tr> </thead> <tbody> <tr> <td>31:01</td><td>Reserved</td></tr> <tr> <td>00</td><td>Zoned Namespace Resource Management (ZNRM): If this bit is set to '1', then the controller supports allocation of resources when creating a zoned namespace (refer to section 4.1.5.4). If this bit is cleared to '0', then the controller does not support allocation of resources when creating a zoned namespace.</td></tr> </tbody> </table>	Bits	Description	31:01	Reserved	00	Zoned Namespace Resource Management (ZNRM): If this bit is set to '1', then the controller supports allocation of resources when creating a zoned namespace (refer to section 4.1.5.4). If this bit is cleared to '0', then the controller does not support allocation of resources when creating a zoned namespace.
Bits	Description							
31:01	Reserved							
00	Zoned Namespace Resource Management (ZNRM): If this bit is set to '1', then the controller supports allocation of resources when creating a zoned namespace (refer to section 4.1.5.4). If this bit is cleared to '0', then the controller does not support allocation of resources when creating a zoned namespace.							
11:08	O ³	Total Active Resources (TAR): This field indicates the total number of active resources (i.e., allocated and unallocated active resources). If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
15:12	O ³	Unallocated Active Resources (UAR): This field indicates the number of unallocated active resources. If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
19:16	O ³	Total Open Resources (TOR): This field indicates the total number of open resources (i.e., allocated and unallocated open resources). If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
23:20	O ³	Unallocated Open Resources (UOR): This field indicates the number of unallocated open resources. If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
27:24	O ³	Total ZRWA Resources (TZRWAR): This field indicates the total number of ZRWA resources (i.e., allocated and unallocated ZRWA resources). If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
31:28	O ³	Unallocated ZRWA Resources (UZRWAR): This field indicates the number of unallocated ZRWA resources. If the ZNRM bit is cleared to '0', then this field should be ignored by the host.						
35:32	M	Version (VER): This field contains a Specification Version Descriptor (refer to the NVM Express Base Specification) indicating the version of this specification supported by the controller, as defined in Figure 52.						
4095:36		Reserved						
Notes:								
1. O/M definition: O = Optional, M = Mandatory.								
2. Mandatory for controllers that support the Zone Append command.								

Published versions of this specification and the values that shall be reported by compliant controllers are defined in Figure 52.

Figure 52: I/O Zoned Namespace Command Set Specification Version Descriptor Field Values

Specification Versions ¹	MJR Field	MNR Field	TER Field
1.0	1h	0h	0h

Figure 52: I/O Zoned Namespace Command Set Specification Version Descriptor Field Values

Specification Versions¹	MJR Field	MNR Field	TER Field
1.1	1h	1h	0h
1.2	1h	2h	0h
1.3	1h	3h	0h
1.4	1h	4h	0h

Notes:

1. The specification version listed includes lettered versions (e.g., 1.1 includes 1.1, 1.1a, 1.1b, etc.).

4.1.5.3 Identify I/O Command Set specific Namespace data structure (CNS 0Ah, CSI 02h)

An I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set (refer to Figure 49) is returned to the host for the Format Index specified by the CNS Specific Identifier field as defined in Figure 53. The returned I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set specifies fields that define capabilities used by a host to format or create a namespace. If the Format Index specified is valid, then the controller shall return an I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set that:

- for fields in Figure 53 that indicate “Yes” in the Reported column, contain a value that is the same for all namespaces using the specified Format Index; and
- for fields in Figure 53 that indicate “No” in the Reported column, contain a value cleared to 0h.

Figure 53: Command Dword 11 - CNS Specific Identifier

Bits	Description
15:0	Format Index (FIDX): This field specifies the Format Index identifying the LBA Format capabilities that are to be returned. Refer to the NVM Command Set Specification.

4.1.5.4 Command Set Index Usage for the Zoned Namespace Command Set

The Zoned Namespace Command Set is an extension to the NVM Command Set as specified in section 1.1. Therefore, the CNS values defined by the NVM Command Set (i.e., 00h) and Zoned Namespace Command Set (i.e., 02h) are used by the host for the Zoned Namespace Command Set.

The following sections provide an example on how a host uses the CSI value 00h and CSI value 02h for accessing Identify Namespace data structures (refer to section 1.4.2.4) for a namespace associated with the Zoned Namespace Command Set.

4.1.5.4.1 Determining the Identify Command Information Associated with a Namespace

For a host to determine the Identify Namespace Data Structures (refer to section 1.4.2.4) for a namespace associated with the Zoned Namespace Command Set, the host is required to issue the following Identify commands in any order:

- a) An Identify command with:
 - a. the CNS field set to 08h; and
 - b. the NSID field set to the NSID of the namespace,
 to access the I/O Command Set Independent Identify Namespace data structure (refer to the NVM Express Base Specification);
- b) An Identify command with:
 - a. the CNS field cleared to 00h; and
 - b. the NSID field set to the NSID of the namespace,
 to access the Identify Namespace data structure (refer to the NVM Command Set Specification);
- c) An Identify command with:
 - a. the CNS field set to 05h;
 - b. the CSI field cleared to 00h; and
 - c. the NSID field set to the NSID of the namespace,

to access the I/O Command Set specific Identify Namespace data structure for the NVM Command Set (refer to the NVM Command Set Specification); and

- d) An Identify command with:

- a. the CNS field set to 05h;
- b. the CSI field set to 02h; and
- c. the NSID field set to the NSID of the namespace,

to access the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set (refer to section 4.1.5.1).

4.1.5.4.2 Determining the Identify Command Information Associated with a Format Index

For a host to determine the Identify Namespace Data Structures associated with a specific Format Index (i.e., determining information about a namespace associated with the Zoned Namespace Command Set prior to creating that namespace), the host is required to issue the following Identify commands in any order:

- a) An Identify command with:

- a. the CNS field set to 08h; and
- b. the NSID field set to FFFFFFFFh,

to access the I/O Command Set Independent Identify Namespace data structure (refer to the NVM Express Base Specification);

- b) An Identify command with:

- a. the CNS field set to 09h;
- b. the CSI field cleared to 00h;
- c. the NSID field cleared to 0h; and
- d. the CNS Specific Identifier field set to the Format Index,

to access the Identify Namespace data structure (refer to the NVM Command Set Specification);

- c) An Identify command with:

- a. the CNS field set to 0Ah;
- b. the CSI field cleared to 00h;
- c. the NSID field cleared to 0h; and
- d. the CNS Specific Identifier field set to the Format Index,

to access the I/O Command Set specific Identify Namespace data structure for the NVM Command Set (refer to the NVM Command Set Specification); and

- d) An Identify command with:

- a. the CNS field set to 0Ah;
- b. the CSI field set to 02h;
- c. the NSID field cleared to 0h; and
- d. the CNS Specific Identifier field set to the Format Index,

to access the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set (refer to section 4.1.5.3).

4.1.6 Namespace Management command

The Namespace Management command operates as defined in the NVM Command Set Specification with the following changes:

- The addition that the Format Index (refer to section 1.4.2.2) also specifies the entry in the LBA Format Extensions list (refer to Figure 49) for zone attributes used to format a created namespace.
- The Host Specified Fields data structure for the Zoned Namespace Command Set is defined in Figure 54.

The Namespace Management command will also operate with the following additional definitions:

- If the value in the RAR field is greater than the value specified in the UAR field (refer to Figure 51), then the controller shall abort the command with a status code of Invalid Field in Command.
- If the value in the ROR field is greater than the value specified in the UOR field (refer to Figure 51), then the controller shall abort the command with a status code of Invalid Field in Command.
- If the value in the RNUMZRWA field is greater than the value specified in the UZRWAR field (refer to Figure 51), then the controller shall abort the command with a status code of Invalid Field in Command.
- If the values in the MAR field, MOR field, and NUMZRWA field (refer to Figure 49) do not meet the requirements specified in section 2.1.1.4, then the controller shall abort the command with a status code of Invalid Namespace or Format.

After successful creation of a namespace, the resource allocated to the namespace are reflected in the Unallocated Active Resources, Unallocated Open Resources and in the Unallocated ZRWA Resources fields.

Figure 54: I/O Namespace Management – Host Specific Fields

Bytes	Description	Host Specified				
Fields that are a subset of the Identify Namespace data structure						
383:00	Refer to the NVM Command Set Specification					
Fields that are not a subset of the Identify Namespace data structure						
498:384	Refer to the NVM Command Set Specification	Yes				
Fields that are not a subset of the Identify Namespace data structure						
499	Zoned Namespace Create Options (ZNSCO):	Yes				
	<table border="1"> <thead> <tr> <th>Bits</th><th>Description</th></tr> </thead> <tbody> <tr> <td>07:01</td><td>Reserved</td></tr> <tr> <td>00</td><td> Allocate ZRWA Resources (AZR): If this bit is set to '1', then the namespace is to be created with the number of ZRWA resource specified in the RNUMZRWA field of this data structure. If this bit is cleared to '0', then no ZRWA resources are allocated to the namespace to be created. If the ZRWASUP bit is cleared to '0' (refer to Figure 49), then this bit shall be ignored by the controller. </td></tr> </tbody> </table>		Bits	Description	07:01	Reserved
Bits	Description					
07:01	Reserved					
00	Allocate ZRWA Resources (AZR): If this bit is set to '1', then the namespace is to be created with the number of ZRWA resource specified in the RNUMZRWA field of this data structure. If this bit is cleared to '0', then no ZRWA resources are allocated to the namespace to be created. If the ZRWASUP bit is cleared to '0' (refer to Figure 49), then this bit shall be ignored by the controller.					
503:500	Requested Active Resources (RAR) ¹ : This field specifies the number of active resources to be allocated to the created namespace. A value of 00000000h specifies the number of Active resources requested to be allocated to the namespace is vendor specific and that number is reflected in the MAR field in the I/O Command Set specific Identify Namespace data structure. Values of 00000001h to FFFFFFFEh specify the number of Active resources requested to be allocated is as defined in section 2.1.1.4 and that number is reflected in the MAR field in the I/O Command Set specific Identify Namespace data structure. A value of FFFFFFFFh specifies the number of Active resources requested to be allocated to the namespace is not limited and that number is reflected in the MAR field in the I/O Command Set specific Identify Namespace data structure.	Yes				
507:504	Requested Open Resources (ROR) ¹ : This field specifies the number of open resources to be allocated to the created namespace. A value of 00000000h specifies the number of Open resources requested to be allocated to the namespace is vendor specific and that number is reflected in the MOR field in the I/O Command Set specific Identify Namespace data structure. Values of 00000001h to FFFFFFFEh specify the number of Open resources requested to be allocated is as defined in section 2.1.1.4 and that number is reflected in the MOR field in the I/O Command Set specific Identify Namespace data structure. A value of FFFFFFFFh specifies the number of Open resources requested to be allocated to the namespace is not limited and that number is reflected in the MOR field in the I/O Command Set specific Identify Namespace data structure.	Yes				

Figure 54: I/O Namespace Management – Host Specific Fields

Bytes	Description	Host Specified
Fields that are a subset of the Identify Namespace data structure		
511:508	<p>Requested Number of ZRWA Resources (RNUMZRWA)¹: This field specifies the number of ZRWA resources to be allocated to the created namespace.</p> <p>A value of 00000000h specifies the number of ZRWA resources requested to be allocated to the namespace is vendor specific and that number is reflected in the NUMZRWA field in the I/O Command Set specific Identify Namespace data structure.</p> <p>Values of 00000001h to FFFFFFFEh specify the number of ZRWA resources requested to be allocated is as defined in section 2.1.1.4 and that number is reflected in the NUMZRWA field in the I/O Command Set specific Identify Namespace data structure.</p> <p>A value of FFFFFFFFh specifies the number of ZRWA resources requested to be allocated to the namespace is not limited and that number is reflected in the NUMZRWA field in the I/O Command Set specific Identify Namespace data structure.</p>	Yes
4095:512	Reserved	

Notes:

1. If Zoned Namespace Resource Management (refer to the ZNRM bit in Figure 51) is not supported, then this field is ignored by the controller.

4.1.6.1 Command Completion

When the command is completed, the controller posts a completion queue entry to the Admin Completion Queue indicating the status for the command.

After successful completion of a Namespace Management command with the create operation, the number of resources allocated with the value requested in the RAR field, may be reflected by a change in the UAR field in the Identify Controller data structure by one or more controllers.

After successful completion of a Namespace Management command with the create operation, the number of resources allocated with the value requested in the ROR field, may be reflected by a change in the UOR field in the Identify Controller data structure by one or more controllers.

After successful completion of a Namespace Management command with the create operation, the number of resources allocated with the value requested in the RNUMZRWA field, may be reflected by a change in the UZRWAR field in the Identify Controller data structure by one or more controllers.

4.1.7 Sanitize command

The Sanitize command operates as defined in the NVM Express Base Specification, with additional requirements for controllers implementing the Zoned Namespace Command Set defined in this section.

All fields of the Sanitize command are as defined in the NVM Express Base Specification.

4.1.8 Sanitize Namespace command

The Sanitize Namespace command operates as defined in the NVM Express Base Specification, with additional requirements for controllers implementing the Zoned Namespace Command Set defined in this section.

All fields of the Sanitize Namespace command are as defined in the NVM Express Base Specification.

4.2 I/O Command Set Specific Admin commands

The I/O command set specific Admin commands are as defined in the NVM Express Base Specification and in the NVM Command Set Specification.

5 Extended Capabilities

5.1 Reservations

Reservations operate as defined the NVM Express Base Specification and the NVM Command Set Specification, with the additional Command Behavior in the Presence of a Reservation defined in Figure 55.

Figure 55: Command Behavior in the Presence of a Reservation

NVMe Command	Write Exclusive Reservation		Exclusive Access Reservation		Write Exclusive Registrants Only or Write Exclusive All Registrants Reservation		Exclusive Access Registrants Only or Exclusive Access All Registrants Reservation	
	Non-Registrant	Registrant	Non-Registrant	Registrant	Non-Registrant	Registrant	Non-Registrant	Registrant
Zoned Namespace Read Command Group								
Zone Management Receive	A	A	C	C	A	A	C	A
Zoned Namespace Write Command Group								
Zone Append	C	C	C	C	C	A	C	A
Zone Management Send								
Key: A definition: A=Allowed, command processed normally by the controller C definition: C=Conflict, command aborted by the controller with a status code of status Reservation Conflict								

5.2 Directives

Support for Directives is as defined the NVM Command Set Specification.

5.3 Zone Descriptor Extension

The Zone Descriptor Extension feature allows a host to associate a small amount of data (e.g., UUID) to a zone. The data is attached to a zone as a Zone Descriptor Extension and is able to be accessed by issuing a Zone Management Receive command with a Zone Receive Action of Extended Report Zones (refer to section 3.4.2.2.2) and specifying that zone. The host may read the Zone Descriptor Extension Valid bit in the Zone Attributes field of that zone to determine if that zone has data associated.

A Zone Descriptor Extension is associated with a zone when the zone is transitioned from the ZSE:Empty state to the ZSC:Closed state as a result of a Zone Management Send command with Zone Send Action of Set Zone Descriptor Extension that specifies that zone and the data to associate in the data buffer (refer to section 3.4.3.1.7).

Upon successful completion of the Zone Management Receive command:

- a) the data in the data buffer is associated with the Zone Descriptor Extension of that zone; and
- b) the Zone Descriptor Extension Valid bit in the Zone Attributes field of that zone is set '1'.

When data has been associated with a Zone Descriptor Extension, the data is associated until:

- a) that zone transitions to the ZSE:Empty state or the ZSO:Offline state; and
- b) the Zone Descriptor Extension Valid bit in the Zone Attributes field of that zone is cleared to '0'.

5.4 Reset Zone Recommended

A controller that schedules an internal operation (e.g., background operation on the non-volatile medium) on a zone that is in the ZSF:Full state may notify the host to initiate a zone reset operation

(refer to section 3.4.3.1.4.1). If a controller schedules such an internal operation on a zone, the controller may notify the host by:

- a) setting the Reset Zone Recommended bit to ‘1’ in the Zone Attributes field of the specific zone (refer to Figure 38);
- b) setting the Reset Zone Recommended Time Limit field in the Zone Attributes Information field to indicate the number of seconds before the controller intends to perform an internal operation on the specified zone; and
- c) generating a Zone Descriptor Changed event for the specific zone.

As a zone reset operation destroys data in a specific zone, it is optional for the host to perform a zone reset operation on zones that have the Reset Zone Recommended bit set to ‘1’ in the Zone Attributes field. If the host does not perform a zone reset operation on the specific zone, then the internal operation, which may impact performance, may be performed.

If the controller has processed the internal operation or the internal operation is no longer scheduled, the controller may notify the host by:

- a) clearing the Reset Zone Recommended bit to ‘0’ in the Zone Attributes field of the specific zone; and
- b) generating a Zone Descriptor Changed event for the specific zone.

If a zone is in the ZSF:Read Only state or the ZSF:Offline state, then the Reset Zone Recommended attribute shall be cleared to ‘0’.

5.5 Finish Zone Recommended

A controller that schedules an internal operation (e.g., background operation on the non-volatile medium) on a zone that is in the:

- a) ZSIO:Implicitly Opened state;
- b) ZSEO:Explicitly Opened state; or
- c) ZSC:Closed state,

may notify the host to either:

- a) initiate a zone finish operation (refer to section 3.4.3.1.2) on that zone; or
- b) initiate write operations to that zone such that the zone transitions to the ZSF:Full state.

The operation initiated by the host may enable the controller to cancel the scheduled internal operation.

The controller may notify the host by:

- a) setting the Finish Zone Recommended bit to ‘1’ in the Zone Attributes field of the specific zone (refer to Figure 38);
- b) setting the Finish Zone Recommended Time Limit field in the Zone Attributes Information field to indicate the number of seconds before the controller intends to perform an internal operation on the specified zone; and
- c) generating a Zone Descriptor Changed event for the specific zone.

It is optional for the host to process the above mitigating actions on zones that have the Finish Zone Recommended bit set to ‘1’ in the Zone Attributes field. If the host does not perform the mitigating actions on the specific zone, then the internal operation, which may impact performance, may be performed.

If the controller has processed the internal operation or the internal operation is no longer scheduled, the controller may notify the host by:

- a) clearing the Finish Zone Recommended bit to ‘0’ in the Zone Attributes field of the specific zone; and
- b) generating a Zone Descriptor Changed event for the specific zone.

If a zone is in the ZSF:Read Only state or the ZSF:Offline state, then the controller shall clear the Finish Zone Recommended bit to ‘0’ in the Zone Attributes field.

5.6 Zone Active Excursions

A Zone Active Excursion is a vendor specific action on a zone that is in the:

- a) ZSIO:Implicitly Opened state;
- b) ZSEO:Explicitly Opened state; or
- c) ZSC:Closed state,

and transitions the zone to the ZSF:Full state. A Zone Active Excursion is orthogonal to the Finish Zone Recommended feature (refer to section 5.5), and can occur at any point when a zone has transitioned to one of the listed zone states. If the controller performs a Zone Active Excursion on such a zone, then the controller shall notify the host by:

- a) setting the Zone Finished by Controller bit to '1' in the Zone Attributes field of that zone (refer to Figure 38); and
- b) generating a Zone Descriptor Changed event for that zone.

If a zone is in the ZSF:Read Only state or the ZSF:Offline state, then the controller shall clear the Zone Finished by Controller bit to '0' in the Zone Attributes field.

5.7 Zone Random Write Area

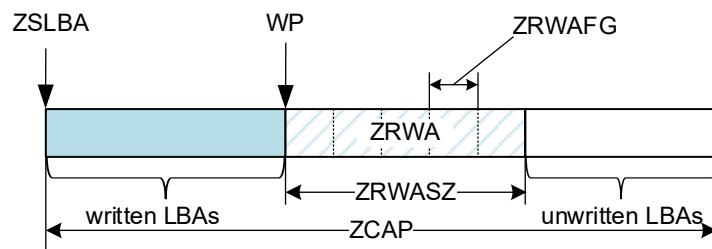
A ZRWA may be thought of as being analogous to a type of non-volatile cache.

Support for ZRWA is optional. If assignment of a ZRWA to a zone is supported, then the ZRWASUP bit shall be set to '1' in the OZCS field in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set. If the ZRWASUP bit is cleared to '0', then assignment of a ZRWA to a zone in the specified namespace is not supported.

The Zone Random Write Area Size (ZRWASZ) field (refer to Figure 8) indicates the size of the ZRWA in logical blocks. The lowest-numbered LBA of the ZRWA is the write pointer of the zone with which the ZRWA is associated. The highest-numbered LBA of the ZRWA is the write pointer of the zone with which the ZRWA is associated plus ZRWASZ minus 1. For a given zone, a ZRWA of size n ends at (write pointer + $n - 1$). ZRWASZ shall be a multiple of ZRWA Flush Granularity (ZRWAFG) (refer to Figure 8), as shown in Figure 56.

The ZRWA advances when the write pointer advances.

Figure 56: Write Pointer in a Partially Written Zone with Associated ZRWA



A ZRWA is allocated to a zone using the Zone Send Management command with a Zone Send Action of Open Zone or Set Zone Descriptor Extension. Allocating a ZRWA to a zone creates an association between the ZRWA and that zone. A ZRWA is associated with at most one zone at a time.

A ZRWA remains associated with a zone until that zone transitions to the ZSF:Full state, ZSE:Empty state, ZSRO:Read Only state, or ZSO:Offline state. A transition to the ZSF:Full state, ZSE:Empty state, ZSRO:Read Only state, or ZSO:Offline state terminates the association, releases the ZRWA associated with that zone, and increases the number of ZRWA resources available for allocation by 1 (refer to the Number of ZRWA Resources field in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set).

For a zone that is associated with a ZRWA:

- a) logical blocks within the ZRWA are not required to be written sequentially; a host may write data to logical block addresses within the ZRWA in any order;
- b) the Starting LBA for an Address-Specific Write Command to the ZRWA is required to be greater than or equal to the write pointer of the zone;

- c) the host is not limited to a single outstanding Address-Specific Write Command at one time to the ZRWA; and
- d) the host may overwrite logical blocks in the ZRWA.

If a zone is associated with a ZRWA, then any Address-Specific Write Command that attempts to address an LBA that is less than the write pointer of that zone shall be aborted with a status code of Invalid Zone Write.

A ZRWA Flush operation (refer to section 5.7.1) is used to flush logical blocks and metadata from a ZRWA to the zone associated with that ZRWA.

The controller shall perform a ZRWA Flush operation prior to transitioning that zone to the ZSF:Full or ZSRO:Read Only state.

Address-Specific Write Commands to logical block addresses in a ZRWA do not cause the associated zones' write pointer to be updated unless that Address-Specific Write Command causes an implicit ZRWA Flush operation to occur.

If a Zone Append command is received for a zone while that zone is associated with a ZRWA, then the controller shall abort the command as described in section 3.4.1.

All writes that start within the ZRWA or the IZFR (refer to section 5.7.3) are allowed to specify LBAs up to the end of the writeable capacity of the zone.

The coordination of host usage of ZRWAs associated with shared namespaces is outside the scope of this specification.

5.7.1 ZRWA Flush Operations

A ZRWA Flush operation flushes user data from a ZRWA (refer to section 1.4.4.10) to a zone and advances the write pointer as described in section 5.7.3. There is a one to one mapping between the source LBA in the ZRWA and the implied destination LBA in the associated zone. Logical blocks which have been flushed are not able to be written again until the zone transitions to the ZSE:Empty state.

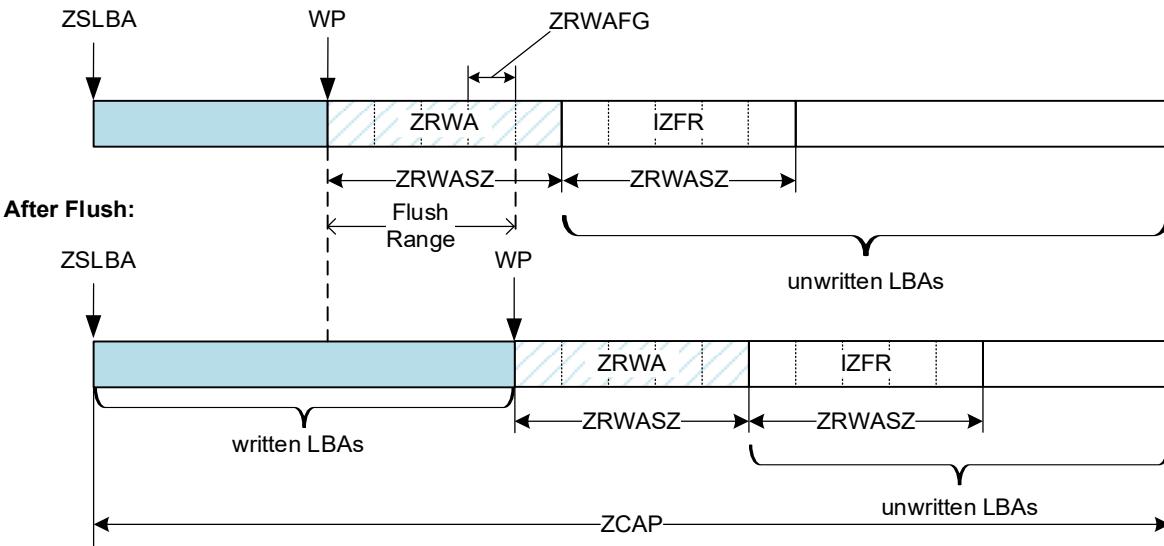
When a ZRWA Flush operation that affects a logical block occurs, if that logical block is unwritten, then that logical block is flushed to the zone as an unwritten logical block (refer to section Deallocated or Unwritten Logical Blocks in the NVM Command Set Specification).

ZRWA Flush operations may be explicit or implicit. Both explicit and implicit ZRWA Flush operations:

- a) flush logical blocks in multiples of ZRWA Flush Granularity (ZRWAFG) from the ZRWA to the zone; and
- b) advance the write pointer by the number of logical blocks flushed to the zone in step a).

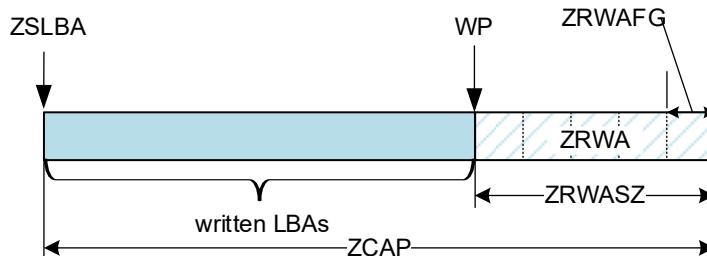
When an explicit ZRWA Flush operation flushes the logical block that causes the zone to reach its writeable zone capacity, the zone shall transition to the ZSF:Full state.

Figure 57 shows the effects of a ZRWA Flush operation on the write pointer and the mapping of the ZRWA to the logical blocks in the zone.

Figure 57: Flush Operation**Before Flush:**

If the ZRWA is at the end of the zone (i.e., $WP \geq ZCAP - ZRWASZ$; refer to Figure 58), then there is no IZFR (refer to section 5.7.3) and implicit ZRWA Flush operations do not occur. If the ZRWA is at the end of the zone, to initiate a ZRWA Flush, the host should send a Zone Management Send command specifying either:

- a Zone Send Action of Finish Zone; or
- a Zone Send Action of Flush Explicit ZRWA Range.

Figure 58: ZRWA at End of Zone

For a namespace that is able to support a ZRWA, the ZCAP field for all zones on that namespace shall be set to a value that is an integral multiple of ZRWA FG.

5.7.2 Explicit ZRWA Flush

An explicit ZRWA Flush operation is performed when a Zone Send Management command with the Zone Send Action field set to Flush Explicit ZRWA Range (refer to section 3.4.3.1.3) completes successfully. The EXPFLUSHSUP bit shall be set to '1' in the I/O Command Set specific Identify Namespace data structure for the Zoned Namespace Command Set if the Flush Explicit ZRWA Range Zone Send Action is supported.

5.7.3 Implicit ZRWA Flush

As a result of an Address-Specific Write Command, multiple implicit ZRWA Flush operations may occur. If one or more implicit ZRWA Flush operations occur as a result of a given Address-Specific Write Command, then at the completion of that Address-Specific Write Command, the write pointer has been updated and all logical blocks up to the new write pointer have been flushed to the associated zone.

The range of logical blocks that starts at the first logical block beyond the end of the ZRWA and is the same size as the ZRWA (ZRWASZ) is called the Implicit ZRWA Flush Range (IZFR) as shown in Figure 59.

Figure 59: Implicit ZRWA Flush Range

Start of Implicit ZRWA Flush Range	End of Implicit ZRWA Flush Range
Write Pointer + ZRWA Size	Write Pointer + (2 * ZRWA Size) – 1

The controller performs an implicit ZRWA Flush when the controller processes an Address-Specific Write Command that specifies one or more logical blocks in the IZFR.

The variables in Figure 60 are used to describe an implicit ZRWA Flush operation.

Figure 60: Implicit ZRWA Flush Variables

Variable	Definition
New_WP	New Write Pointer
WP	Initial Write Pointer
IZFR_Start_LBA	Start of IZFR (i.e., WP + ZRWASZ)
Last_LBA	Ending LBA in Write Operation
FG	ZRWA Flush Granularity (ZRWA FG)

The range of LBAs flushed by an implicit ZRWA Flush operation begins with the write pointer. The number of logical blocks flushed is an integral multiple of the ZRWA FG and is at least one times ZRWA FG.

If an implicit ZRWA Flush operation occurs, then the value of the write pointer is determined by the following formula:

$$\begin{aligned} \text{if } & ((\text{Last_LBA} - \text{IZFR_Start_LBA}) \bmod \text{FG}) > 0 \\ \text{then } & \text{New_WP} = \text{WP} + \text{Ceiling} \left(\frac{\text{Last_LBA} - \text{IZFR_Start_LBA}}{\text{FG}} \right) * \text{FG} \\ \text{else } & \text{New_WP} = \text{WP} + (\text{Ceiling} \left(\frac{\text{Last_LBA} - \text{IZFR_Start_LBA}}{\text{FG}} \right) + 1) * \text{FG} \end{aligned}$$

If an Address-Specific Write Command specifies a Starting LBA that is greater than or equal to *IZFR_Start_LBA* + ZRWASZ (i.e., the first LBA after the IZFR) then the controller shall abort that command with a status code of Zone Invalid Write, and shall not perform any implicit ZRWA Flush operations.

If an implicit ZRWA Flush operation is to be performed, then that implicit ZRWA Flush operation shall be performed whether or not the Address-Specific Write Command completes successfully.

5.8 Sanitize Operations

The Sanitize Status (SSTAT) field in the Sanitize Status log page (refer to the NVM Express Base Specification) and the zone state for all zones in a zoned namespace that results from a successful sanitize operation:

- for an NVM subsystem sanitize operation (refer to the NVM Express Base Specification) are defined in Figure 61; and
- for a namespace sanitize operation (refer to the NVM Express Base Specification) are defined in Figure 62.

The resulting zone state of all zones and status to report as a result of a successful NVM subsystem sanitize operation is dependent on the setting of the:

- a) No Deallocate After Sanitize bit in the Sanitize command that requested the sanitize operation;
- b) No-Deallocate Modifies Media After Sanitize field in the Identify Controller data structure;
- c) No-Deallocate Inhibited bit in the Identify Controller data structure;

- d) No-Deallocate Response Mode bit in the Sanitize Config feature (refer to the NVM Express Base Specification); and
- e) Sanitize Action field in the Sanitize command that requested the NVM subsystem sanitize operation.

Figure 61: Sanitize NVM Subsystem Behavior for the Zoned Namespace Command Set

No Deallocate After Sanitize	No-Deallocate Modifies Media After Sanitize (NODMMAS)	No- Deallocate Inhibited (NDI)	No-Deallocate Response Mode (NODRM)	Results of a successful NVM subsystem sanitize operation		
				Zone State ¹	Logical Block Content ²	Sanitize Status ⁴
0b	n/a ³	n/a ³	n/a ³	ZSE:Empty	Refer to section 2.1.1.2.1.2	001b
1b	00b	0b	n/a ³	ZSE:Empty	Refer to section 2.1.1.2.1.2	001b
1b	00b	1b	0b			n/a ⁵
1b	00b	1b	1b	ZSE:Empty	Refer to section 2.1.1.2.1.2	001b
1b	01b (does not modify)	0b (not inhibited)	n/a ³	ZSF:Full	Note 6	001b
1b	01b	1b (inhibited)	1b	ZSE:Empty	Refer to section 2.1.1.2.1.2	100b
1b	01b	1b	0b			n/a ⁵
1b	10b (does modify)	0b	n/a ³	ZSF:Full	Note 6	001b
1b	10b	1b	1b	ZSE:Empty	Refer to section 2.1.1.2.1.2	100b
1b	10b	1b	0b			n/a ⁵
n/a ³	11b	n/a ³	n/a ³	Reserved		

Notes:

1. ZSO:Offline state is a valid zone state as a result of a successful sanitize operation.
2. This field describes the read value from a deallocated logical block. Refer to the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification.
3. This value is not relevant in the setup conditions defined in that row.
4. Value reported in the Sanitize Operation Status (SOS) field of the Sanitize Status (SSTAT) field in the Sanitize Status log page (refer to the NVM Express Base Specification).
5. Sanitize command is aborted with a status code of Invalid Field in Command.
6. Block Erase and Crypto Erase are not defined in this specification; Overwrite shall be the overwrite pattern specified in the Sanitize command that requested the NVM subsystem sanitize operation.

The resulting zone state as a result of a successful namespace sanitize operation is defined in Figure 62.

Figure 62: Sanitize Namespace Behavior for the Zoned Namespace Command Set

Results of a successful namespace sanitize operation		
Zone State ¹	Logical Block Content ²	Sanitize Status ³
ZSE:Empty	Refer to section 2.1.1.2.1.2	001b
Notes:		
1.	ZSO:Offline state is a valid zone state as a result of a successful namespace sanitize operation.	
2.	This field describes the read value from a deallocated logical block. Refer to the Deallocated or Unwritten Logical Blocks section in the NVM Command Set Specification.	
3.	Value reported in the Sanitize Operation Status (SOS) field of the Sanitize Status (SSTAT) field in the Sanitize Status log page (Log Page Identifier 81h) (refer to the NVM Express Base Specification).	

If the NVM subsystem is in the Media Verification state (refer to the Sanitize Operations section of the NVM Express Base Specification), then the logical block content is described in the Media Verification section of the NVM Express NVM Command Set Specification.

Annex A. Zoned Namespaces Host Considerations (Normative)

A.1 Introduction

The Zoned Namespace Command Set defines host management requirements in addition to those defined in the NVM Command Set.

To facilitate better interactions between hosts and NVM subsystems, this annex describes the Zoned Namespaces feature from a host perspective.

A.2 Writing to Zones

In a Sequential Write Required zone, writes to a zone are required to start at the valid write pointer address if a ZRWA is not associated with a zone. Refer to section 5.7 for more details.

A.3 Open Zone Considerations

A.3.1 Overview

Each zone that is in either the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state has both Active Resources and Open Resources associated. Limitations on the availability of Active Resources and Open Resources and the number of zones allowed in these zone states are indicated by the Maximum Open Resources field and the Maximum Active Resources field.

Each zone that is in the ZSC:Closed state has only Active Resources associated. Availability of Active Resources and the number of zones allowed in this zone state are indicated by the Maximum Active Resources field.

If a write operation is processed on LBAs in a zone in the ZSE:Empty state or the ZSC:Closed state, then that zone shall be managed as if that zone is requested to transition to the ZSIO:Implicitly Opened state and shall account for Active Resources and Open Resources as defined in section 2.1.1.2.

A zone remains in the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state until:

- a) a write operation specifying that zone is processed that causes that zone to reach its writeable zone capacity;
- b) the zone state is ZSIO:Implicitly Opened state, and that zone is selected by the controller (which zone is selected is vendor specific) to transition to the ZSC:Closed state;
- c) a Zone Management Send command specifying that zone and specifying a Zone Send Action of Finish Zone completes successfully;
- d) a Zone Management Send command specifying that zone and specifying a Zone Send Action of Reset Zone completes successfully;
- e) a Zone Management Send command specifying that zone and specifying a Zone Send Action of Close Zone completes successfully;
- f) the controller transitions the state of that zone to the ZSRO:Read Only state or the ZSO:Offline state;
- g) the controller transitions that zone to the ZSF:Full state due to a Zone Active Excursion; and
- h) an NVM Subsystem Reset occurs (refer to the Resets section of the NVM Express Base Specification).

A.3.2 Zones in the ZSEO:Explicitly Opened Zones and the ZSIO:Implicitly Opened states

An open zone is a zone that is in either the ZSIO:Implicitly Opened state or the ZSEO:Explicitly Opened state. For a zone that is in either the ZSE:Empty state or ZSC:Closed state, the controller transitions that zone to:

- a) ZSEO:Explicitly Opened state as a result of processing a Zone Management Send command with Zone Send Action of Open Zone; or
- b) ZSIO:Implicitly Opened state as a result of processing a write operation.

If a controller processes a Zone Management Send command with Zone Send Action of Open Zone on a zone in the ZSC:Closed state, then the controller transitions that zone to the ZSEO:Explicitly Opened state.

For resource management purposes, the controller may transition a zone in the ZSIO:Implicitly Opened state to the ZSC:Closed state in order to move the active resource associated with that zone to a different zone that is transitioning into the ZSIO:Implicitly Opened state.

A.3.3 Opening and Closing Zones

A host may use the following techniques to open a zone for writing and following that to close that zone:

- a) Issue a Zone Management Send command with Zone Send Action of Open Zone to transition a zone to the ZSEO:Explicitly Opened state, and following that the host may issue a Zone Management Send command with Zone Send Action of Close Zone to transition that zone to the ZSC:Closed state; or
- b) Issue a write operation to open a zone, and following that the host may issue a Zone Management Send command with Zone Send Action of Close Zone to transition that zone to the ZSC:Closed state.

The controller may autonomously transition any zone from the ZSIO:Implicitly Opened state to the ZSC:Closed state.

A host may use multiple Zone Management Send commands with Zone Send Action of Close Zone to close more zones than the number necessary to satisfy limitations on the number of zones that may be open.

A.3.4 Zone Send Action of Finish Zone Considerations

A zone may be opened (e.g., with a Zone Management Send command with Zone Send Action of Open Zone) prior to processing a Zone Management Send command with Zone Send Action of Finish Zone.

Regardless of how a zone is opened before processing a Zone Management Send command with Zone Send Action of Finish Zone, completion of the command transitions the zone to the ZSF:Full state, with the result that Active and Open Resources become available.

A.4 Partial Failures

A.4.1 Overview

The zone state ZSRO:Read Only provides the ability for a host to continue using a zoned namespace after part of the capacity of the zone has stopped operating (e.g., the controller transitions a zone to the ZSRO:Read Only state as a response to a media failure).

After a zone enters the ZSRO:Read Only state, the host should perform the following actions:

- 1) Transfer the data from that zone to another location (e.g., by using the Copy command); and
- 2) Transition that zone to the ZSO:Offline state by issuing a Zone Management Send command with a Zone Send Action of Offline Zone.

A.5 Capacity and Sizes

There are several data structures involved in size and capacity reporting:

Figure 63: Size and Capacity Fields

Data Structure	Field	Bytes	Description
Identify Namespace Data Structure, NVM Command Set (CNS 00h)	Namespace Size (NSZE)	7:0	(NSZE-1) indicates the highest possible LBA in the zoned namespace
	Namespace Capacity (NCAP)	15:8	The maximum number of allocatable logical blocks in the zoned namespace
	Formatted LBA Size (FLBAS)	26	Index into the list of LBA formats. Refer to the NVM Command Set Specification.
	LBA Format XX (LBAFXX)	191:128	LBADS field indicates the logical block data size (in bytes) (as a power of 2). MS field indicates the metadata size (in bytes).

Figure 63: Size and Capacity Fields

Data Structure	Field	Bytes	Description
Zoned Namespace Command Set specific Identify Namespace	LBA Format Extension XX (LBAFEXT)	3839:2816	ZDES indicates the size of the Zone Descriptor Extension (as a multiple of 64 bytes). ZSZE indicates the number of logical blocks of each zone of the zoned namespace.
Zone Descriptor	Zone Capacity (ZCAP)	15:8	Indicates the maximum number of logical blocks that may be written in the zone associated with the data descriptor.

A zone has a size (ZSZE) and a capacity (ZCAP) that are related to optional support for the variable zone capacity feature. ZCAP may change as a result of resetting the write pointer. Refer to Figure 64.

A zone transitions to the ZSF:Full after successful completion of a write operation that includes $LBA = (ZSLBA + ZCAP_{CURRENT} - 1)$, in addition to other events (e.g., successful completion of a Zone Management Send command with a Zone Send Action of Finish Zone).

Figure 64: Zone Size Relationships