SPC BENCHMARK 1™
FULL DISCLOSURE REPORT

IBM CORPORATION
IBM STORWIZE® V7000 *(SSDS)*

SPC-1 V1.12

Submitted for Review: June 4, 2012
Submission Identifier: A00116

First Edition – June 2012

Trademarks

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AUDIT CERTIFICATION

Bruce McNutt
IBM Corporation
650 Harry Road
San Jose, CA 95120

June 1, 2012

The SPC Benchmark 1™ Reported Data listed below for the IBM Storwize® V7000 *(SSDs)* was produced in compliance with the SPC Benchmark 1™ v1.12 Remote Audit requirements.

SPC Benchmark 1™ v1.12 Reported Data	
Tested Storage Product (TSP) Name: IBM Storwize® V7000 *(SSDs)*	
Metric	**Reported Result**
SPC-1 IOPS™	120,492.34
SPC-1 Price-Performance	$1.50/SPC-1 IOPS™
Total ASU Capacity	1,527.100 GB
Data Protection Level	Protected *(Mirroring)*
Total TSC Price (including three-year maintenance)	$181,029.02

The following SPC Benchmark 1™ Remote Audit requirements were reviewed and found compliant with 1.12 of the SPC Benchmark 1™ specification:

- A Letter of Good Faith, signed by a senior executive.
- The following Data Repository storage items were verified by information supplied by IBM Corporation:
  - ✓ Physical Storage Capacity and requirements.
  - ✓ Configured Storage Capacity and requirements.
  - ✓ Addressable Storage Capacity and requirements.
  - ✓ Capacity of each Logical Volume and requirements.
  - ✓ Capacity of each Application Storage Unit (ASU) and requirements.
- The total Application Storage Unit (ASU) Capacity was filled with random data, using an auditor approved tool, prior to execution of the SPC-1 Tests.
- An appropriate diagram of the Benchmark Configuration (BC)/Tested Storage Configuration (TSC).

Storage Performance Council
643 Bair Island Road, Suite 103
Redwood City, CA 94062
AuditService@storageperformance.org
650.556.9384

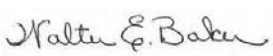
AUDIT CERTIFICATION *(CONT.)*

- Listings and commands to configure the Benchmark Configuration/Tested Storage Configuration, including customer tunable parameters that were changed from default values.
- SPC-1 Workload Generator commands and parameters used for the audited SPC Test Runs.
- The following Host System requirements were verified by information supplied by IBM Corporation:
  - ✓ The type of each Host System including the number of processors and main memory.
  - ✓ The presence and version number of the SPC-1 Workload Generator on each Host System.
  - ✓ The TSC boundary within each Host System.
- The Test Results Files and resultant Summary Results Files received from IBM Corporation for each of following were authentic, accurate, and compliant with all of the requirements and constraints of Clauses 4 and 5 of the SPC-1 Benchmark Specification:
  - ✓ Data Persistence Test
  - ✓ Sustainability Test Phase
  - ✓ IOPS Test Phase
  - ✓ Response Time Ramp Test Phase
  - ✓ Repeatability Test
- The differences between the Tested Storage Configuration and Priced Storage Configuration were documented and, if applied to the Tested Storage Configuration, would not have an impact on the audited benchmark measurements.
- The submitted pricing information met all of the requirements and constraints of Clause 8 of the SPC-1 Benchmark Specification.
- The Full Disclosure Report (FDR) met all of the requirements in Clause 9 of the SPC-1 Benchmark Specification.
- This successfully audited SPC measurement is not subject to an SPC Confidential Review.

Audit Notes:

There were no audit notes or exceptions.

Respectfully,



Walter E. Baker
SPC Auditor

Storage Performance Council
643 Bair Island Road, Suite 103
Redwood City, CA 94062
AuditService@storageperformance.org
650.556.9384

LETTER OF GOOD FAITH

IBM

Vice President and Disk Storage Business Line Executive

IBM Technology & Systems Group
3039 Cornwallis Road,
Research Triangle Park, NC 27709

Phone 1-919-543-6345
Fax: 1-919-543-2856

March 30, 2012

Mr. Walter E. Baker, SPC Auditor
Gradient Systems, Inc.
643 Bair Island Road, Suite 103
Redwood City, CA 94063

Subject: SPC-1 Letter of Good Faith for the IBM Storwize V7000 with SSDs.

IBM Corporation is the SPC-1 Test Sponsor for the above listed product. To the best of our knowledge and belief, the required SPC-1 benchmark results and materials we have submitted for that product are complete, accurate, and in full compliance with Version 1.12 of the SPC-1 benchmark specification.

Our disclosure of the Benchmark configuration and execution of the benchmark includes all items that, to the best of our knowledge and belief, materially affect the reported results, regardless of whether such items are explicitly required to be disclosed by the SPC-1 benchmark specification.

Sincerely,

Doug Balog

EXECUTIVE SUMMARY

Test Sponsor and Contact Information

Test Sponsor and Contact Information	
Test Sponsor Primary Contact	IBM Corporation – http://www.ibm.com Bruce McNutt – bmcnutt@us.ibm.com IBM ARC 650 Harry Road San Jose, CA 95120
Test Sponsor Alternate Contact	IBM Corporation – http://www.ibm.com Yijie Zhang – yijie@us.ibm.com 9000 Rita Road IBM Mail Drop 9042-2 Tucson, AZ 85744
Auditor	Storage Performance Council – http://www.storageperformance.org Walter E. Baker – AuditService@StoragePerformance.org 643 Bair Island Road, Suite 103 Redwood City, CA 94063 Phone: (650) 556-9384 FAX: (650) 556-9385

Revision Information and Key Dates

Revision Information and Key Dates	
SPC-1 Specification revision number	V1.12
SPC-1 Workload Generator revision number	V2.2.0
Date Results were first used publicly	June 4, 2012
Date the FDR was submitted to the SPC	June 4, 2012
Date the Priced Storage Configuration is available for shipment to customers	currently available
Date the TSC completed audit certification	June 1, 2012

Tested Storage Product (TSP) Description

The IBM Storwize V7000 disk system, IBM's newest midrange disk storage offering, uses IBM System Storage SAN Volume Controller technology to deliver high performance, advanced function, high availability, and modular and scalable storage capacity.

- Supports RAID 0, 1, 5, 6, and 10
- Provides SAN-attached 8 Gbps Fibre Channel (FC) host connectivity and 1 GbE iSCSI host connectivity
- Accommodates up to twenty-four 2.5-inch disk drives or twelve 3.5-inch disk drives installed within the IBM Storwize V7000 Control Enclosure with attachment support for up to nine IBM Storwize V7000 Expansion Enclosures, providing modular and highly scalable storage solutions that range up to 360 TB physical storage capacity.
- Supports intermix of SAS drives, Nearline SAS drives, and Solid-state drives within the IBM Storwize V7000 Control Enclosure and IBM Storwize V7000 Expansion Enclosures.
- Includes IBM Easy Tier technology for automatically moving heavily used data extents onto high-performance storage
- Supports attachment of other storage devices via the Fibre Channel interface, just as the SAN Volume Controller
- Supports a complete set of SAN Volume Controller functions including FlashCopy, RemoteCopy, VDisk Mirroring, thin provisioning, and a revised web-based user interface for both products new with this release

Summary of Results

SPC-1 Reported Data	
Tested Storage Product (TSP) Name: IBM Storwize® V7000 *(SSDs)*	
Metric	**Reported Result**
SPC-1 IOPS™	120,492.34
SPC-1 Price-Performance™	$1.50/SPC-1 IOPS™
Total ASU Capacity	1,527.100 GB
Data Protection Level	Protected *(Mirroring)*
Total TSC Price (including three-year maintenance)	$181,029.02

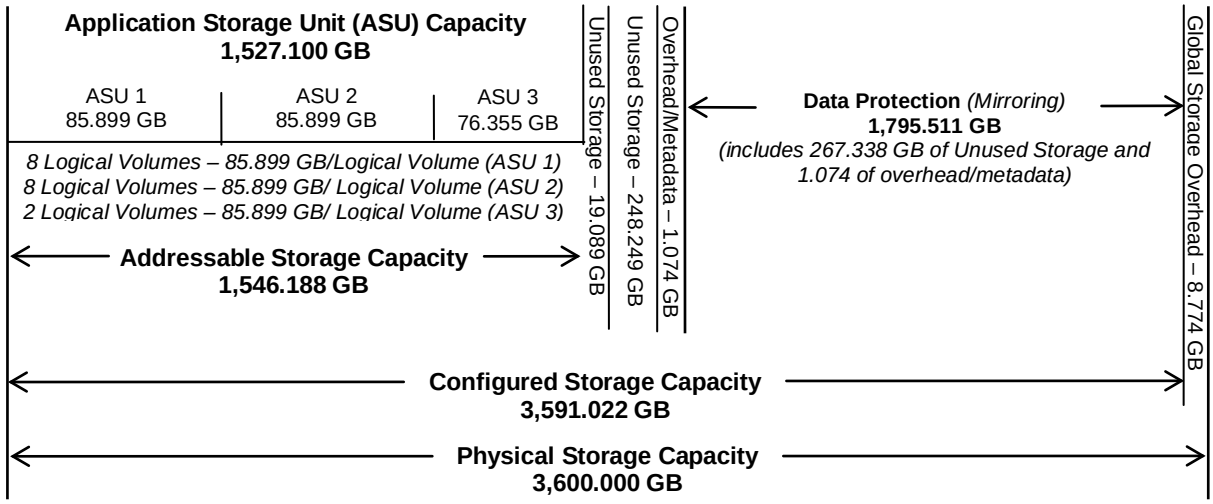
SPC-1 IOPS™ represents the maximum I/O Request Throughput at the 100% load point.

Total ASU (Application Storage Unit) **Capacity** represents the total storage capacity read and written in the course of executing the SPC-1 benchmark.

A **Data Protection Level** of **Protected *Mirroring*** configures two or more identical copies of user data.

Storage Capacities, Relationships, and Utilization

The following diagram and table document the various storage capacities, used in this benchmark, and their relationships, as well as the storage utilization values required to be reported.



SPC-1 Storage Capacity Utilization	
Application Utilization	42.42%
Protected Application Utilization	84.87%
Unused Storage Ratio	14.85%

Application Utilization: Total ASU Capacity *(1,527.100 GB)* divided by Physical Storage Capacity *(3,600.000 GB)*

Protected Application Utilization: Total ASU Capacity *(1,527.100 GB)* plus total Data Protection Capacity *(1,795.511 GB)* minus unused Data Protection Capacity *(214.963 GB)* divided by Physical Storage Capacity *(3,600.000 GB)*

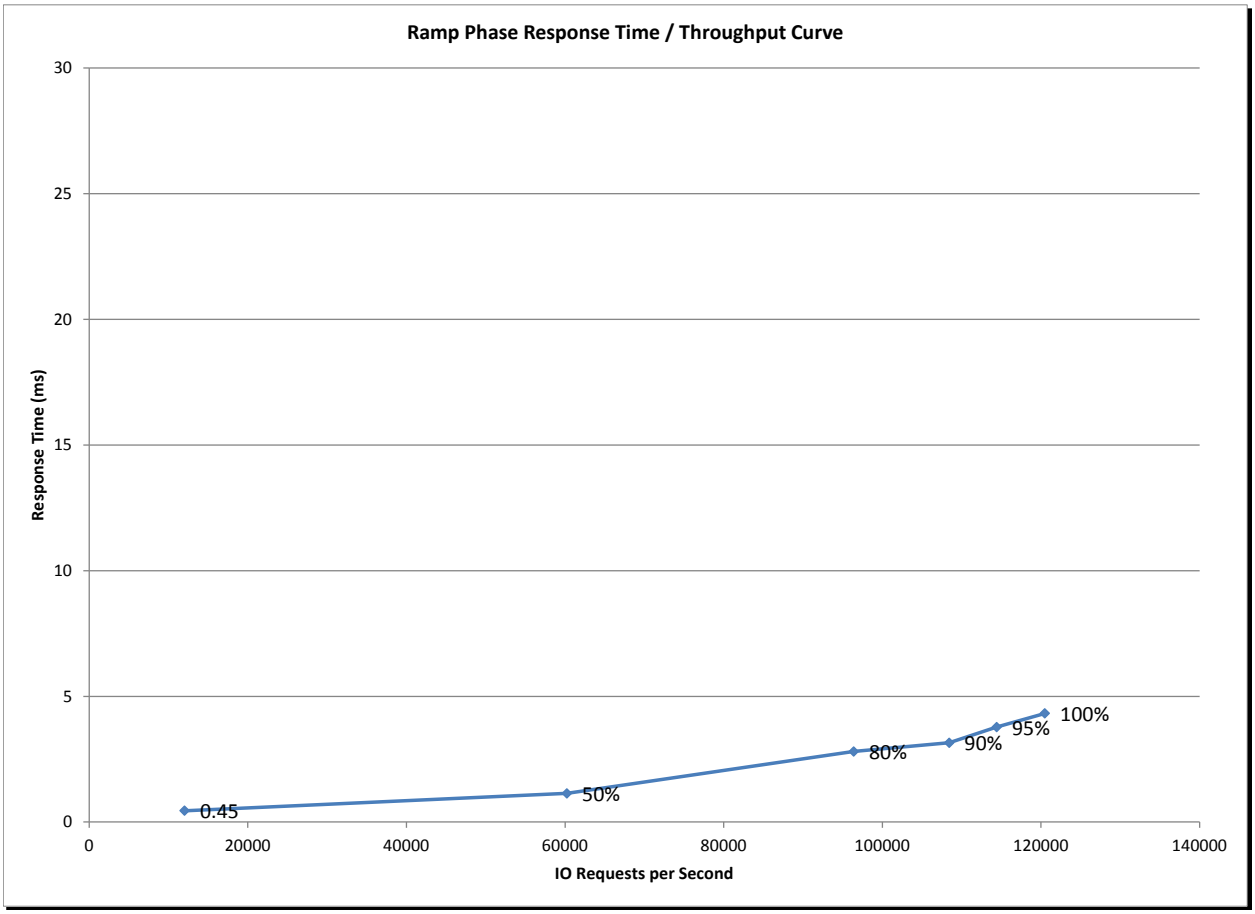
Unused Storage Ratio: Total Unused Capacity *(515.587 GB)* divided by Physical Storage Capacity *(3,600.000 GB)* and may not exceed 45%.

Detailed information for the various storage capacities and utilizations is available on pages 20-21 in the Full Disclosure Report.

Response Time – Throughput Curve

The Response Time-Throughput Curve illustrates the Average Response Time (milliseconds) and I/O Request Throughput at 100%, 95%, 90%, 80%, 50%, and 10% of the workload level used to generate the SPC-1 IOPS™ metric.

The Average Response Time measured at any of the above load points cannot exceed 30 milliseconds or the benchmark measurement is invalid.



Response Time – Throughput Data

	10% Load	50% Load	80% Load	90% Load	95% Load	100% Load
I/O Request Throughput	12,048.96	60,240.56	96,406.36	108,442.25	114,430.47	120,492.34
Average Response Time (ms):						
All ASUs	0.45	1.14	2.80	3.15	3.78	4.32
ASU-1	0.42	1.03	2.44	2.78	3.32	3.80
ASU-2	0.46	1.09	2.59	2.92	3.49	3.99
ASU-3	0.50	1.39	3.68	4.05	4.87	5.55
Reads	0.41	0.87	1.73	2.05	2.41	2.79
Writes	0.47	1.32	3.51	3.87	4.67	5.31

Priced Storage Configuration Pricing

Component	Quantity	Unit Price	Unit Maint	List w/ Maint	% discount	Total Price
V7000 controller (2076-124) w/8 SFPs, 18 - 200GB SSDs	1	186,982.00	4,200.00	191,182.00	39	116,621.02
V7000 base software	1	18,000.00	7,200.00	25,200.00	39	15,372.00
24 port fibre channel switch (2498-B24) w/8 ports enabled, 8 SFPs	2	7,120.00	10,800.00	35,840.00	20	28,672.00
5m fibre channel cable (2076-124 5305)	8	129.00	0.00	1,032.00	20	825.60
25m fibre channel cable (2076-124 5625)	8	189.00	0.00	1,512.00	20	1,209.60
4 Gbps dual port FC adapter (9117-5774)	8	3,273.00	0.00	26,184.00	30	18,328.80
Total Price						**181,029.02**

The above pricing includes hardware maintenance and software support for three years, 7 days per week, 24 hours per day. The hardware maintenance and software support provides the following:

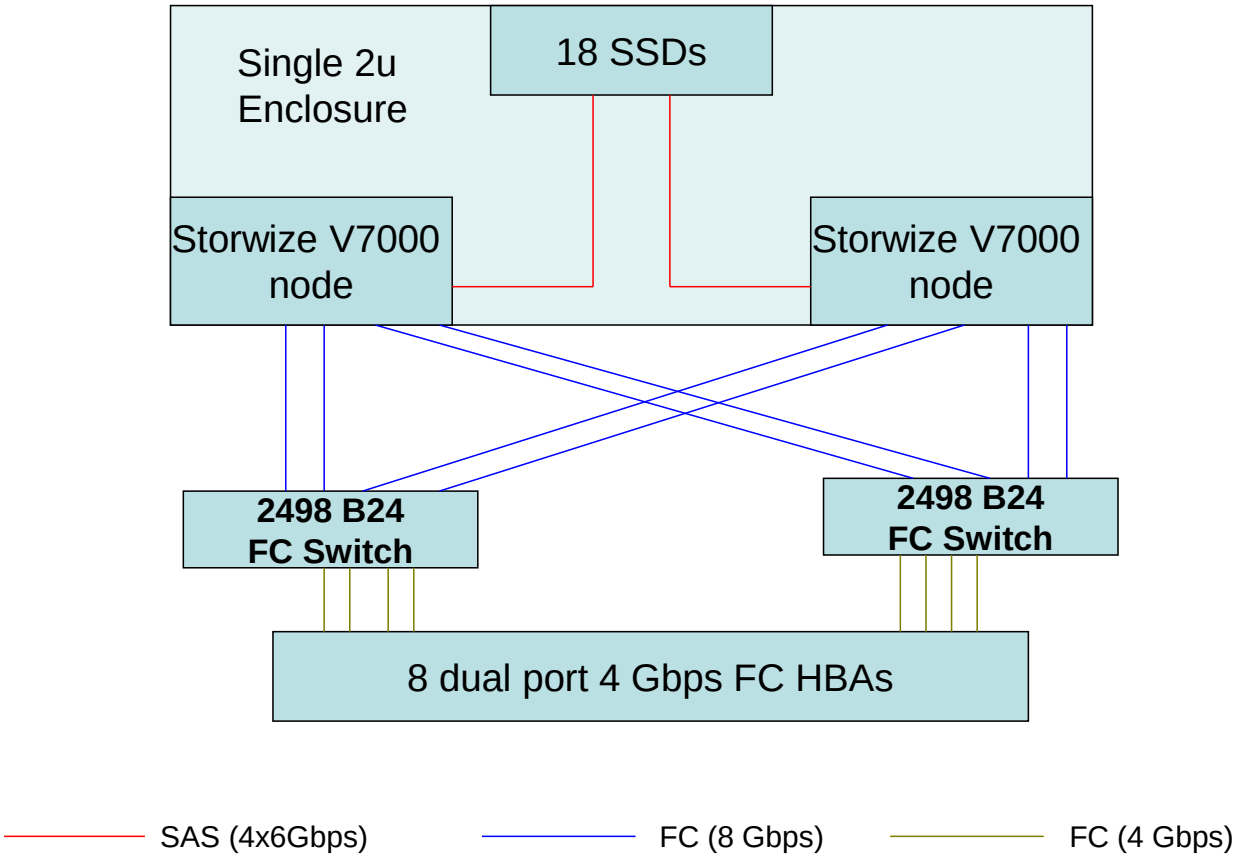
- Acknowledgement of new and existing problems with four (4) hours.
- Onsite presence of a qualified maintenance engineer or provision of a customer replaceable part within four (4) hours of the above acknowledgement for any hardware failure that results in an inoperative Price Storage Configuration that can be remedied by the repair or replacement of a Priced Storage Configuration component.

Differences between the Tested Storage Configuration (TSC) and Priced Storage Configuration

The two 2498 B4 switches used in the TSC was configured with all 24 ports enabled and with 24 SFPs. Only eight of the ports, in each switch, were used in the SPC-1 measurements. Each of the two switches in the priced storage configuration was priced with eight ports enabled and eight SFPs.

This difference, if applied to the TSC, would not have had any impact on the SPC-1 measurements.

Priced Storage Configuration Diagram



Priced Storage Configuration Components

Priced Storage Configuration:
8 – 4 Gbps dual port FC HBAs
IBM Storwize® V7000 *(2 nodes)* Each V7000 node includes: 8 GB cache *(16 GB total)* 4 – 8 Gbps FC front-end connections *(8 total, 8 used)* 2 – 4x6 Gbps SAS backend connections *(4 total, 2 used – 1 per node)*
2 – 24 port Fibre Channel Brocade switches each with 8 ports enabled and 8 SFPs
1 – V7000 Expansion Enclosure
18 – 200 GB Solid State Devices (SSDs)

In each of the following sections of this document, the appropriate Full Disclosure Report requirement, from the SPC-1 benchmark specification, is stated in italics followed by the information to fulfill the stated requirement.

CONFIGURATION INFORMATION

Benchmark Configuration (BC)/Tested Storage Configuration (TSC) Diagram

Clause 9.4.3.4.1

A one page Benchmark Configuration (BC)/Tested Storage Configuration (TSC) diagram shall be included in the FDR…

The Benchmark Configuration (BC)/Tested Storage Configuration (TSC) is illustrated on page 18 *(Benchmark Configuration/Tested Storage Configuration Diagram).*

Storage Network Configuration

Clause 9.4.3.4.1

…

5. *If the TSC contains network storage, the diagram will include the network configuration. If a single diagram is not sufficient to illustrate both the Benchmark Configuration and network configuration in sufficient detail, the Benchmark Configuration diagram will include a high-level network illustration as shown in Figure 9-8. In that case, a separate, detailed network configuration diagram will also be included as described in Clause 9.4.3.4.2.*

Clause 9.4.3.4.2

If a storage network was configured as a part of the Tested Storage Configuration and the Benchmark Configuration diagram described in Clause 9.4.3.4.1 contains a high-level illustration of the network configuration, the Executive Summary will contain a one page topology diagram of the storage network as illustrated in Figure 9-9.

The *Benchmark Configuration/Tested Storage Configuration Diagram*, on page 18, also illustrates the storage network configuration.

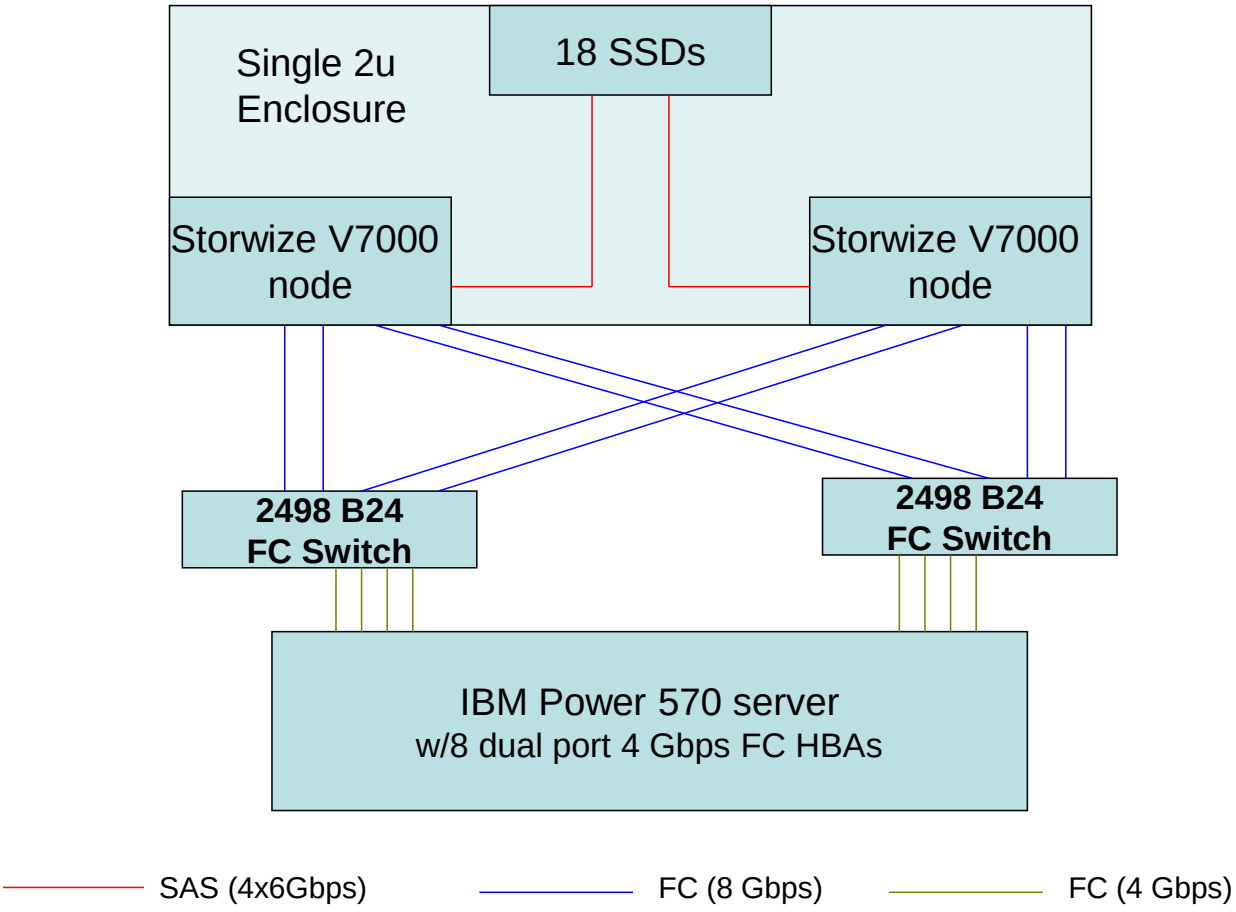
Host System and Tested Storage Configuration (TSC) Table of Components

Clause 9.4.3.4.3

The FDR will contain a table that lists the major components of each Host System and the Tested Storage Configuration (TSC). Table 9-10 specifies the content, format, and appearance of the table.

The Host System and TSC table of components may be found on page 18 *(Host Systems and Tested Storage Configuration Components).*

Benchmark Configuration/Tested Storage Configuration Diagram



Host Systems and Tested Storage Configuration Components

Host System:	Tested Storage Configuration (TSC)
2 – IBM Power® 570 server 16 CPUs (cores) with 1.9 GHz, 32 KB L1 cache, 18 MB L3 cache per CPU 128 GB main memory AIX 6.1 TL4 PCIe	8 – 4 Gbps dual port FC HBAs
	IBM Storwize® V7000 *(2 nodes)* Each V7000 node includes: 8 GB cache *(16 GB total)* 4 – 8 Gbps FC front-end connections *(8 total, 8 used)* 2 – 4x6 Gbps SAS backend connections *(4 total, 2 used – 1 per node)*
	2 – 24 port Fibre Channel Brocade switches each with 8 ports enabled and 8 SFPs
	1 – V7000 Expansion Enclosure
	18 – 200 GB Solid State Devices (SSDs)

Customer Tunable Parameters and Options

Clause 9.4.3.5.1

All Benchmark Configuration (BC) components with customer tunable parameter and options that have been altered from their default values must be listed in the FDR. The FDR entry for each of those components must include both the name of the component and the altered value of the parameter or option. If the parameter name is not self-explanatory to a knowledgeable practitioner, a brief description of the parameter's use must also be included in the FDR entry.

"Appendix B: Customer Tunable Parameters and Options" on page 59 contains the customer tunable parameters and options that have been altered from their default values for this benchmark.

Tested Storage Configuration (TSC) Description

Clause 9.4.3.5.2

The FDR must include sufficient information to recreate the logical representation of the TSC. In addition to customer tunable parameters and options (Clause 4.2.4.5.3), that information must include, at a minimum:

- *A diagram and/or description of the following:*
  - *All physical components that comprise the TSC. Those components are also illustrated in the BC Configuration Diagram in Clause 9.2.4.4.1 and/or the Storage Network Configuration Diagram in Clause 9.2.4.4.2.*
  - *The logical representation of the TSC, configured from the above components that will be presented to the Workload Generator.*
- *Listings of scripts used to create the logical representation of the TSC.*
- *If scripts were not used, a description of the process used with sufficient detail to recreate the logical representation of the TSC.*

"Appendix C: Tested Storage Configuration (TSC) Creation" on page 60 contains the detailed information that describes how to create and configure the logical TSC.

SPC-1 Workload Generator Storage Configuration

Clause 9.4.3.5.3

The FDR must include all SPC-1 Workload Generator storage configuration commands and parameters.

The SPC-1 Workload Generator storage configuration commands and parameters for this measurement appear in "Appendix D: SPC-1 Workload Generator Storage Commands and Parameters" on page 65.

SPC-1 DATA REPOSITORY

This portion of the Full Disclosure Report presents the detailed information that fully documents the various SPC-1 storage capacities and mappings used in the Tested Storage Configuration. "SPC-1 Data Repository Definitions" on page 55 contains definitions of terms specific to the SPC-1 Data Repository.

Storage Capacities and Relationships

Clause 9.4.3.6.1

Two tables and an illustration documenting the storage capacities and relationships of the SPC-1 Storage Hierarchy (Clause 2.1) shall be included in the FDR.

SPC-1 Storage Capacities

SPC-1 Storage Capacities		
Storage Hierarchy Component	**Units**	**Capacity**
Total ASU Capacity	Gigabytes (GB)	1,527.100
Addressable Storage Capacity	Gigabytes (GB)	1,546.188
Configured Storage Capacity	Gigabytes (GB)	3,591.022
Physical Storage Capacity	Gigabytes (GB)	3,600.000
Data Protection *(Mirroring)*	Gigabytes (GB)	1,795.511
Required Storage	Gigabytes (GB)	2.351
Global Storage Overhead	Gigabytes (GB)	8.774
Total Unused Storage	Gigabytes (GB)	534.676

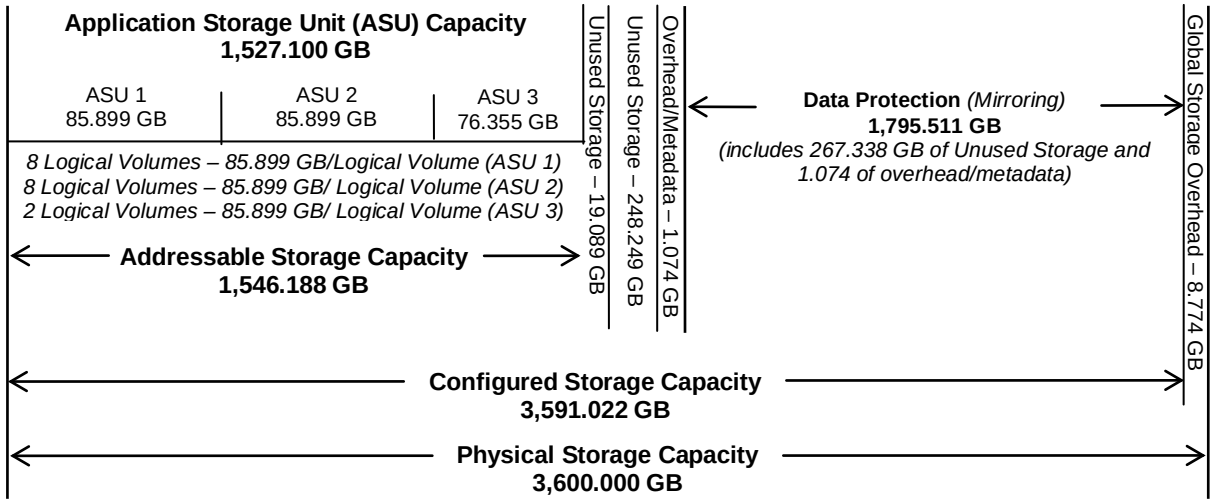
SPC-1 Storage Hierarchy Ratios

	Addressable Storage Capacity	**Configured Storage Capacity**	**Physical Storage Capacity**
Total ASU Capacity	98.77%	42.53%	42.42%
Required for Data Protection *(Mirroring)*		50.00%	49.88%
Addressable Storage Capacity		43.06%	42.95%
Required Storage *(overhead/metadata)*		0.07%	0.07%
Configured Storage Capacity			99.75%
Global Storage Overhead			0.24%
Unused Storage:			
Addressable	1.23%		
Configured		13.83%	
Physical			0.00%

The Physical Storage Capacity consisted of 3,600.00 GB distributed over 18 solid state devices (SSDs), each with a formatted capacity of 200.00 GB. There was 0.000 GB (0.00%) of Unused Storage within the Physical Storage Capacity. Global Storage Overhead consisted of 8.774 GB (0.24%) of the Physical Storage Capacity. There was 4.96.498 GB (13.83%) of Unused Storage within the Configured Storage Capacity. The Total ASU Capacity utilized 98.77% of the Addressable Storage Capacity resulting in 19.089 GB (1.23%) of Unused Storage within the Addressable Storage Capacity. The Data Protection *(Mirroring)* capacity was 1,795.511 GB of which 1527.100GB was utilized. The total Unused Storage was 534.676 GB.

SPC-1 Storage Capacities and Relationships Illustration

The various storage capacities configured in the benchmark result are illustrated below *(not to scale)*.



Logical Volume Capacity and ASU Mapping

Clause 9.4.3.6.3

A table illustrating the capacity of each ASU and the mapping of Logical Volumes to ASUs shall be provided in the FDR. … Logical Volumes shall be sequenced in the table from top to bottom per its position in the contiguous address space of each ASU. The capacity of each Logical Volume shall be stated. … In conjunction with this table, the Test Sponsor shall provide a complete description of the type of data protection (see Clause 2.4.5) used on each Logical Volume.

Logical Volume Capacity and Mapping		
ASU-1 (687.195 GB)	**ASU-2 (687.195 GB)**	**ASU-3 (152.710 GB)**
8 Logical Volumes 85.899 GB per Logical Volume (85.899 GB used per Logical Volume)	8 Logical Volumes 85.899 GB per Logical Volume (85.899 GB used per Logical Volume)	2 Logical Volumes 85.899 GB per Logical Volume (76.355 GB used per Logical Volume)

The Data Protection Level used for all Logical Volumes was "Mirrored" as described on page 12. See "ASU Configuration" in the **IOPS Test Results File** for more detailed configuration information.

Storage Capacity Utilization

Clause 9.4.3.6.2

The FDR will include a table illustrating the storage capacity utilization values defined for Application Utilization (Clause 2.8.1), Protected Application Utilization (Clause 2.8.2), and Unused Storage Ratio (Clause 2.8.3).

Clause 2.8.1

Application Utilization is defined as Total ASU Capacity divided by Physical Storage Capacity.

Clause 2.8.2

Protected Application Utilization is defined as (Total ASU Capacity plus total Data Protection Capacity minus unused Data Protection Capacity) divided by Physical Storage Capacity.

Clause 2.8.3

Unused Storage Ratio is defined as Total Unused Capacity divided by Physical Storage Capacity and may not exceed 45%.

SPC-1 Storage Capacity Utilization	
Application Utilization	42.42%
Protected Application Utilization	84.87%
Unused Storage Ratio	14.85%

SPC-1 BENCHMARK EXECUTION RESULTS

This portion of the Full Disclosure Report documents the results of the various SPC-1 Tests, Test Phases, and Test Runs. "SPC-1 Test Execution Definitions" on page 56 contains definitions of terms specific to the SPC-1 Tests, Test Phases, and Test Runs.

Clause 5.4.3

The Tests must be executed in the following sequence: Primary Metrics, Repeatability, and Data Persistence. That required sequence must be uninterrupted from the start of Primary Metrics to the completion of Persistence Test Run 1. Uninterrupted means the Benchmark Configuration shall not be power cycled, restarted, disturbed, altered, or adjusted during the above measurement sequence. If the required sequence is interrupted other than for the Host System/TSC power cycle between the two Persistence Test Runs, the measurement is invalid.

SPC-1 Tests, Test Phases, and Test Runs

The SPC-1 benchmark consists of the following Tests, Test Phases, and Test Runs:

- **Primary Metrics Test**
  - Sustainability Test Phase and Test Run
  - IOPS Test Phase and Test Run
  - Response Time Ramp Test Phase
    - 95% of IOPS Test Run
    - 90% of IOPS Test Run
    - 80% of IOPS Test Run
    - 50% of IOPS Test Run
    - 10% of IOPS Test Run (LRT)
- **Repeatability Test**
  - Repeatability Test Phase 1
    - 10% of IOPS Test Run (LRT)
    - IOPS Test Run
  - Repeatability Test Phase 2
    - 10% of IOPS Test Run (LRT)
    - IOPS Test Run
- **Data Persistence Test**
  - Data Persistence Test Run 1
  - Data Persistence Test Run 2

Each Test is an atomic unit that must be executed from start to finish before any other Test, Test Phase, or Test Run may be executed.

The results from each Test, Test Phase, and Test Run are listed below along with a more detailed explanation of each component.

Primary Metrics Test – Sustainability Test Phase

Clause 5.4.4.1.1

The Sustainability Test Phase has exactly one Test Run and shall demonstrate the maximum sustainable I/O Request Throughput within at least a continuous three (3) hour Measurement Interval. This Test Phase also serves to insure that the TSC has reached Steady State prior to reporting the final maximum I/O Request Throughput result (SPC-1 IOPS™).

Clause 5.4.4.1.2

The computed I/O Request Throughput of the Sustainability Test must be within 5% of the reported SPC-1 IOPS™ result.

Clause 5.4.4.1.4

The Average Response Time, as defined in Clause 5.1.1, will be computed and reported for the Sustainability Test Run and cannot exceed 30 milliseconds. If the Average Response time exceeds that 30-milliseconds constraint, the measurement is invalid.

Clause 9.4.3.7.1

For the Sustainability Test Phase the FDR shall contain:

1. *A Data Rate Distribution graph and data table.*
2. *I/O Request Throughput Distribution graph and data table.*
3. *A Response Time Frequency Distribution graph and table.*
4. *An Average Response Time Distribution graph and table.*
5. *The human readable Test Run Results File produced by the Workload Generator (may be included in an appendix).*
6. *A listing or screen image of all input parameters supplied to the Workload Generator (may be included in an appendix).*
7. *The Measured Intensity Multiplier for each I/O stream.*
8. *The variability of the Measured Intensity Multiplier, as defined in Clause 5.3.13.3.*

SPC-1 Workload Generator Input Parameters

The SPC-1 Workload Generator input parameters for the Sustainability, IOPS, Response Time Ramp, Repeatability, and Persistence Test Runs are documented in "Appendix E: SPC-1 Workload Generator Input Parameters" on Page 66.

Sustainability Test Results File

A link to the test results file generated from the Sustainability Test Run is listed below.

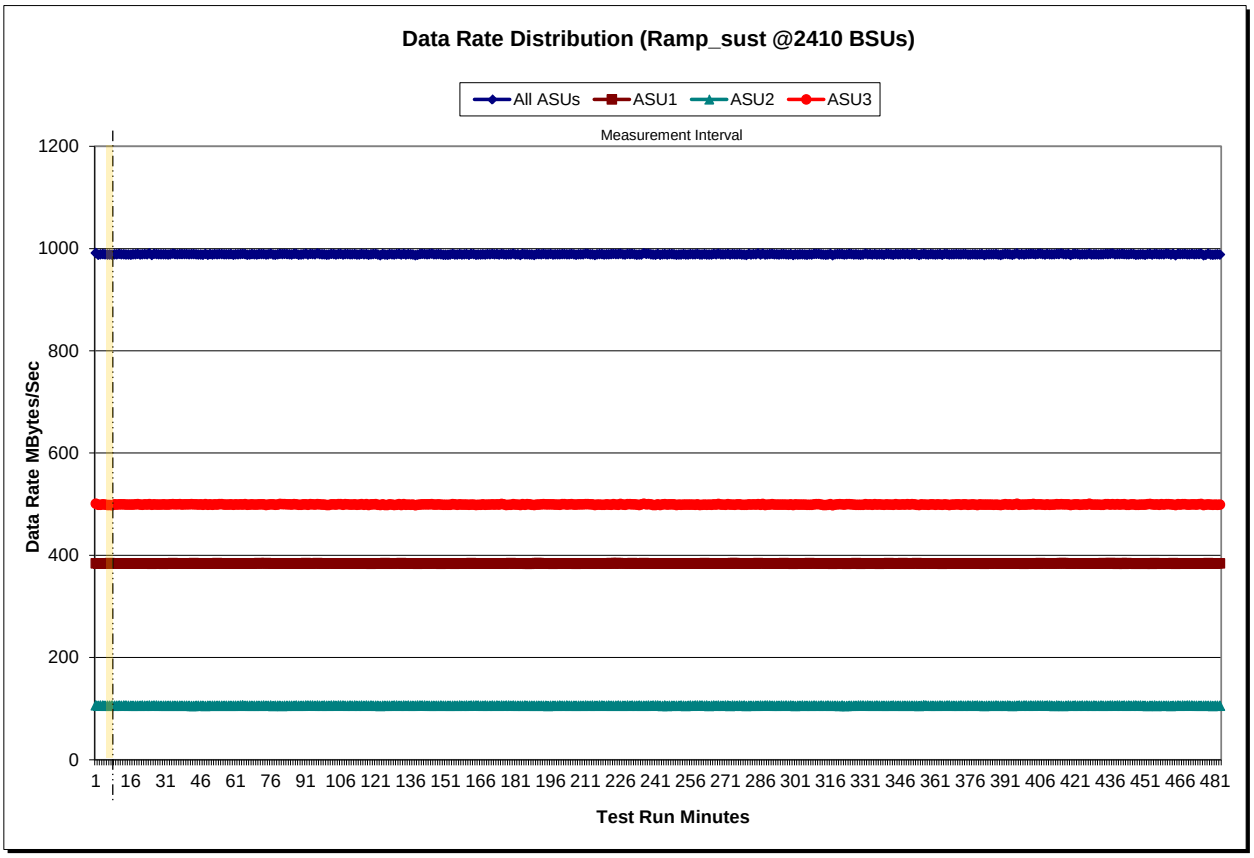
Sustainability Test Results File

Sustainability – Data Rate Distribution Data *(MB/second)*

The Sustainability Data Rate table of data is not embedded in this document due to its size. The table is available via the following URL:

Sustainability Data Tables

Sustainability – Data Rate Distribution Graph

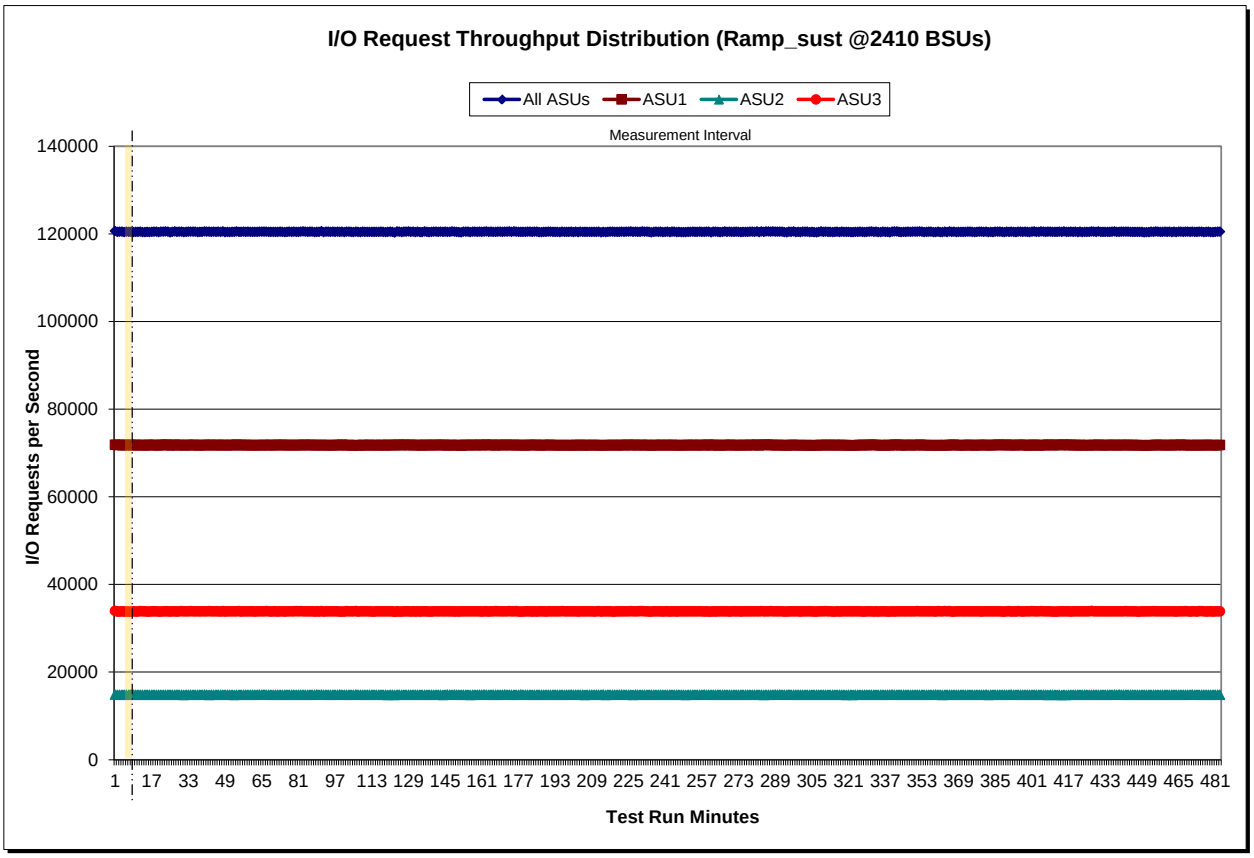


Sustainability – I/O Request Throughput Distribution Data

The Sustainability I/O Request Throughput table of data is not embedded in this document due to its size. The table is available via the following URL:

Sustainability Data Tables

Sustainability – I/O Request Throughput Distribution Graph

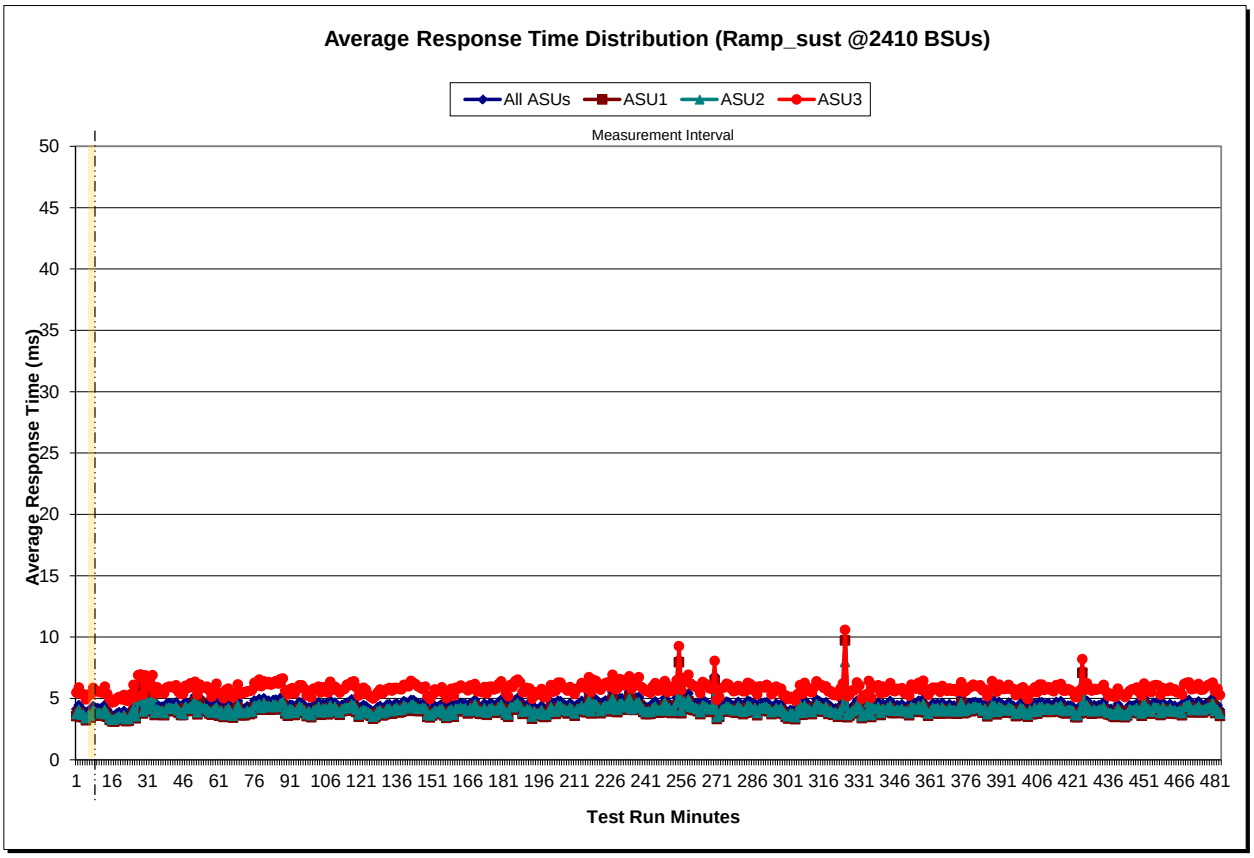


Sustainability – Average Response Time (ms) Distribution Data

The Sustainability Average Response Time table of data is not embedded in this document due to its size. The table is available via the following URL:

Sustainability Data Tables

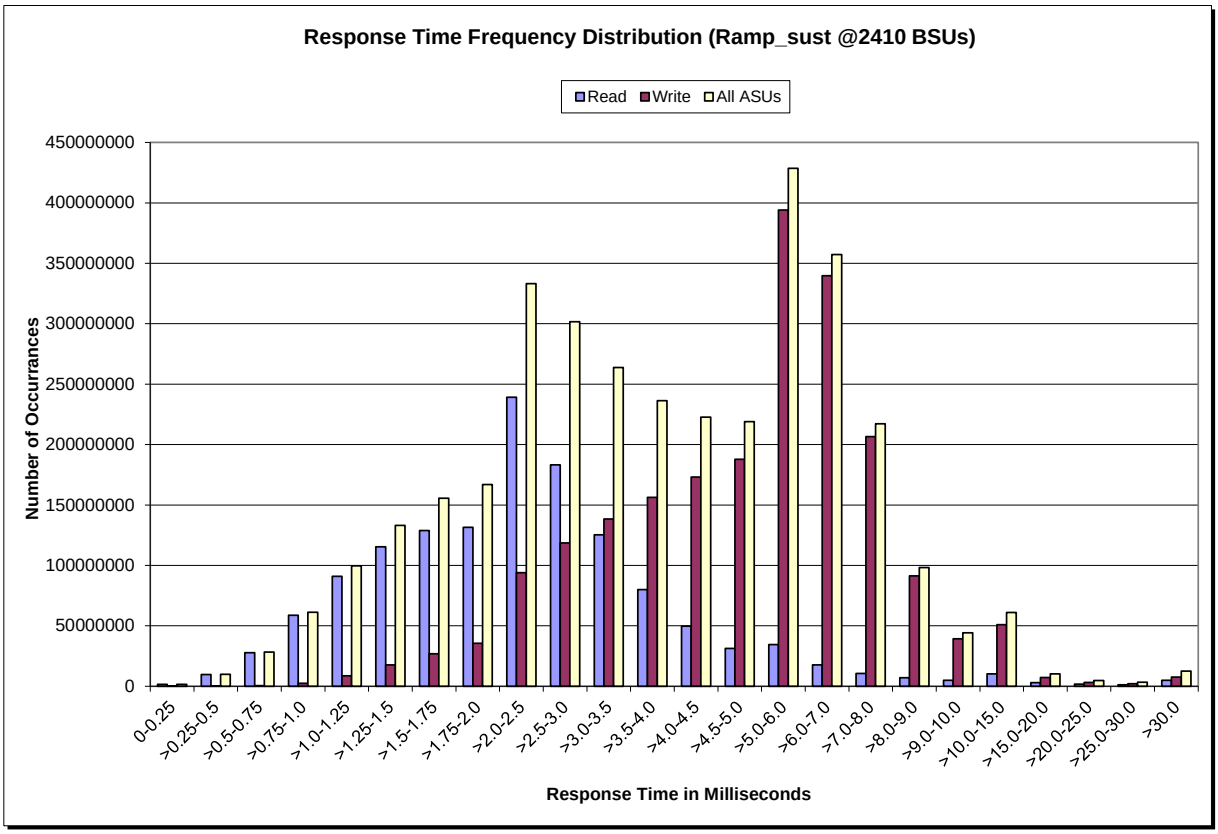
Sustainability – Average Response Time (ms) Distribution Graph



Sustainability – Response Time Frequency Distribution Data

Response Time (ms)	0-0.25	>0.25-0.5	>0.5-0.75	>0.75-1.0	>1.0-1.25	>1.25-1.5	>1.5-1.75	>1.75-2.0
Read	1,488,995	9,707,839	27,808,448	58,710,124	91,007,335	115,468,177	128,886,703	131,421,821
Write	2,583	142,189	464,360	2,506,524	8,707,012	17,590,306	26,785,374	35,529,565
All ASUs	1,491,578	9,850,028	28,272,808	61,216,648	99,714,347	133,058,483	155,672,077	166,951,386
ASU1	1,408,067	8,945,304	24,648,501	51,929,539	82,243,655	106,913,246	122,206,282	128,018,367
ASU2	82,800	851,258	3,448,192	8,363,981	14,131,017	19,116,618	22,476,647	24,119,168
ASU3	711	53,466	176,115	923,128	3,339,675	7,028,619	10,989,148	14,813,851
Response Time (ms)	**>2.0-2.5**	**>2.5-3.0**	**>3.0-3.5**	**>3.5-4.0**	**>4.0-4.5**	**>4.5-5.0**	**>5.0-6.0**	**>6.0-7.0**
Read	239,176,648	183,221,628	125,296,674	79,983,099	49,709,119	31,239,184	34,425,622	17,640,929
Write	93,908,721	118,516,985	138,437,042	156,360,141	173,046,277	187,764,714	394,086,749	339,682,899
All ASUs	333,085,369	301,738,613	263,733,716	236,343,240	222,755,396	219,003,898	428,512,371	357,323,828
ASU1	245,495,699	208,517,005	168,206,537	138,023,917	120,085,684	111,143,884	205,679,272	162,619,073
ASU2	47,768,806	42,301,921	35,583,116	30,288,302	27,092,933	25,496,992	47,664,256	37,755,627
ASU3	39,820,864	50,919,687	59,944,063	68,031,021	75,576,779	82,363,022	175,168,843	156,949,128
Response Time (ms)	**>7.0-8.0**	**>8.0-9.0**	**>9.0-10.0**	**>10.0-15.0**	**>15.0-20.0**	**>20.0-25.0**	**>25.0-30.0**	**>30.0**
Read	10,519,309	6,972,161	4,903,398	10,142,930	3,058,021	1,669,350	1,270,129	4,959,262
Write	206,632,166	91,258,777	39,325,212	50,886,882	7,213,889	3,154,611	2,104,894	7,657,594
All ASUs	217,151,475	98,230,938	44,228,610	61,029,812	10,271,910	4,823,961	3,375,023	12,616,856
ASU1	92,062,355	36,672,787	14,172,591	22,026,151	5,215,736	2,666,147	1,948,261	7,533,850
ASU2	21,175,597	8,169,282	2,961,292	4,593,085	1,115,869	560,387	397,256	1,394,051
ASU3	103,913,523	53,388,869	27,094,727	34,410,576	3,940,305	1,597,427	1,029,506	3,688,955

Sustainability – Response Time Frequency Distribution Graph



Sustainability – Measured Intensity Multiplier and Coefficient of Variation

Clause 3.4.3

IM – Intensity Multiplier: *The ratio of I/Os for each I/O stream relative to the total I/Os for all I/O streams (ASU1-1 – ASU3-1) as required by the benchmark specification.*

Clauses 5.1.10 and 5.3.13.2

MIM – Measured Intensity Multiplier: *The Measured Intensity Multiplier represents the ratio of measured I/Os for each I/O stream relative to the total I/Os measured for all I/O streams (ASU1-1 – ASU3-1). This value may differ from the corresponding Expected Intensity Multiplier by no more than 5%.*

Clause 5.3.13.3

COV – Coefficient of Variation: *This measure of variation for the Measured Intensity Multiplier cannot exceed 0.2.*

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2810	0.0700	0.2100	0-.0180	0.0700	0.0350	0.2810
COV	0.002	0.001	0.001	0.001	0.003	0.001	0.002	0.001

Primary Metrics Test – IOPS Test Phase

Clause 5.4.4.2

The IOPS Test Phase consists of one Test Run at the 100% load point with a Measurement Interval of ten (10) minutes. The IOPS Test Phase immediately follows the Sustainability Test Phase without any interruption or manual intervention.

The IOPS Test Run generates the SPC-1 IOPS™ primary metric, which is computed as the I/O Request Throughput for the Measurement Interval of the IOPS Test Run.

The Average Response Time is computed for the IOPS Test Run and cannot exceed 30 milliseconds. If the Average Response Time exceeds the 30 millisecond constraint, the measurement is invalid.

Clause 9.4.3.7.2

For the IOPS Test Phase the FDR shall contain:

1. *I/O Request Throughput Distribution (data and graph).*
2. *A Response Time Frequency Distribution.*
3. *An Average Response Time Distribution.*
4. *The human readable Test Run Results File produced by the Workload Generator.*
5. *A listing or screen image of all input parameters supplied to the Workload Generator.*
6. *The total number of I/O Requests completed in the Measurement Interval as well as the number of I/O Requests with a Response Time less than or equal to 30 milliseconds and the number of I/O Requests with a Response Time greater than 30 milliseconds.*

SPC-1 Workload Generator Input Parameters

The SPC-1 Workload Generator input parameters for the Sustainability, IOPS, Response Time Ramp, Repeatability, and Persistence Test Runs are documented in "Appendix E: SPC-1 Workload Generator Input Parameters" on Page 66.

IOPS Test Results File

A link to the test results file generated from the IOPS Test Run is listed below.

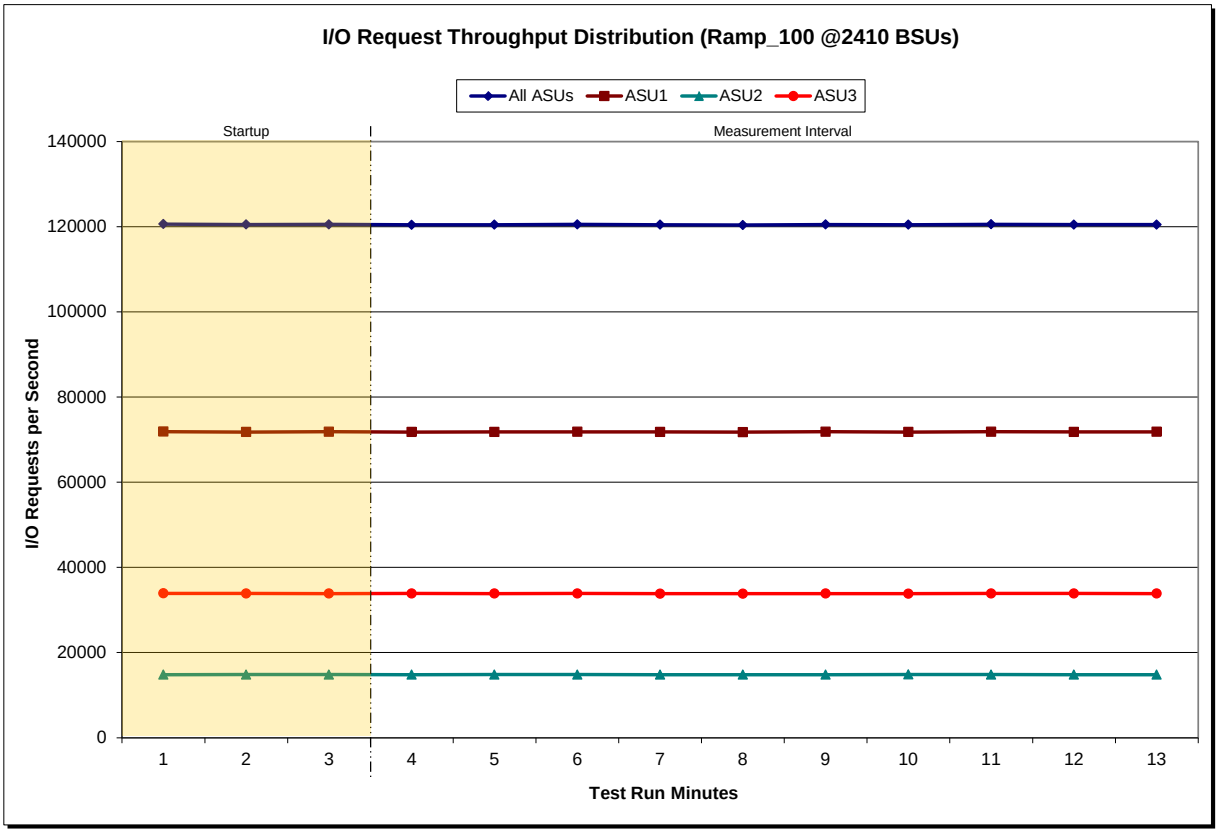
IOPS Test Results File

IOPS Test Run – I/O Request Throughput Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	16:56:03	16:59:04	0-2	0:03:01
Measurement Interval	16:59:04	17:09:04	3-12	0:10:00

60 second intervals	All ASUs	ASU1	ASU2	ASU3
0	120,628.12	71,897.92	14,823.10	33,907.10
1	120,515.15	71,799.53	14,830.37	33,885.25
2	120,552.57	71,858.52	14,843.68	33,850.37
3	120,453.38	71,782.45	14,799.10	33,871.83
4	120,483.77	71,801.73	14,832.20	33,849.83
5	120,546.50	71,840.53	14,833.58	33,872.38
6	120,467.65	71,817.58	14,819.32	33,830.75
7	120,408.30	71,762.67	14,806.52	33,839.12
8	120,519.63	71,853.18	14,815.80	33,850.65
9	120,477.18	71,776.35	14,861.93	33,838.90
10	120,570.92	71,862.07	14,824.12	33,884.73
11	120,508.22	71,807.55	14,816.97	33,883.70
12	120,487.88	71,838.62	14,799.02	33,850.25
Average	*120,492.34*	*71,814.27*	*14,820.86*	*33,857.22*

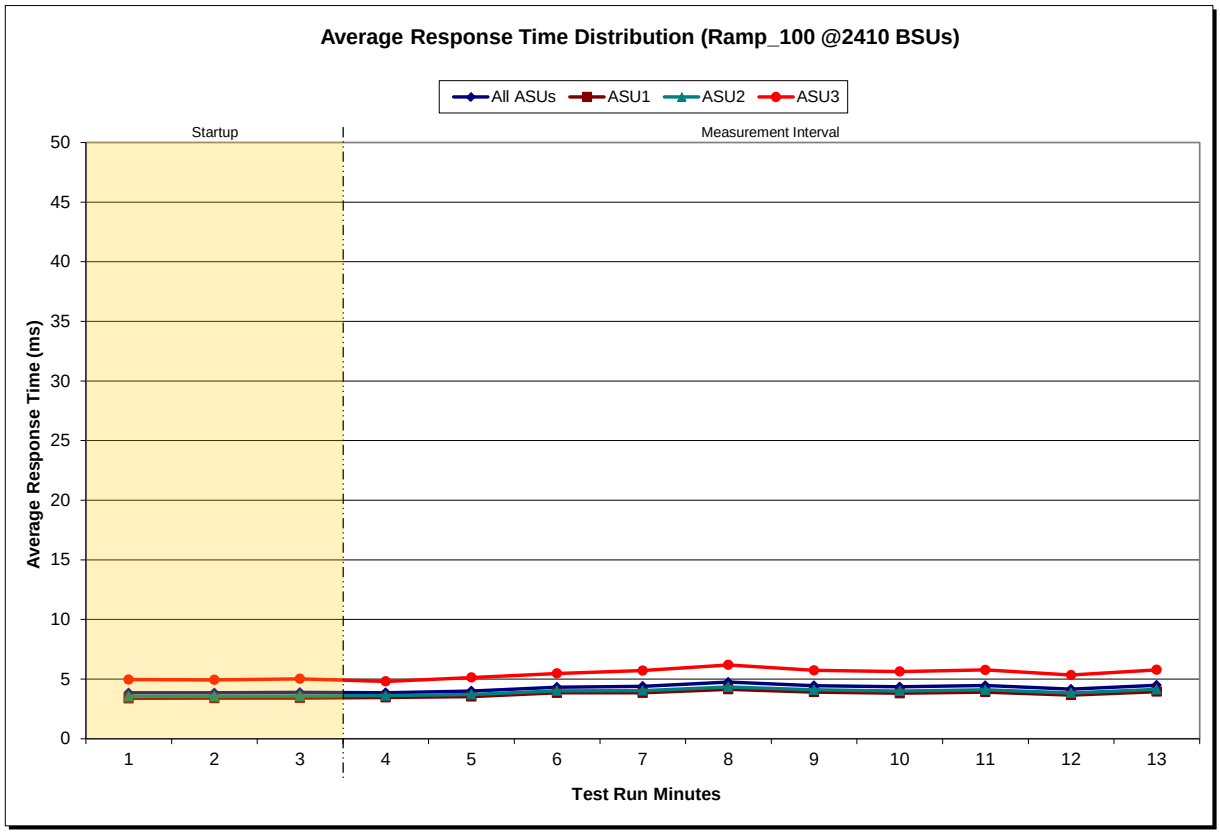
IOPS Test Run – I/O Request Throughput Distribution Graph



IOPS Test Run – Average Response Time (ms) Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	16:56:03	16:59:04	0-2	0:03:01
Measurement Interval	16:59:04	17:09:04	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	3.84	3.38	3.55	4.96
1	3.85	3.40	3.56	4.93
2	3.88	3.41	3.58	5.02
3	3.86	3.46	3.61	4.81
4	4.00	3.53	3.71	5.13
5	4.32	3.84	4.01	5.47
6	4.40	3.85	4.04	5.72
7	4.74	4.14	4.34	6.19
8	4.44	3.91	4.09	5.73
9	4.35	3.81	4.00	5.63
10	4.45	3.91	4.10	5.77
11	4.15	3.66	3.84	5.33
12	4.48	3.94	4.13	5.78
Average	***4.32***	***3.80***	***3.99***	***5.55***

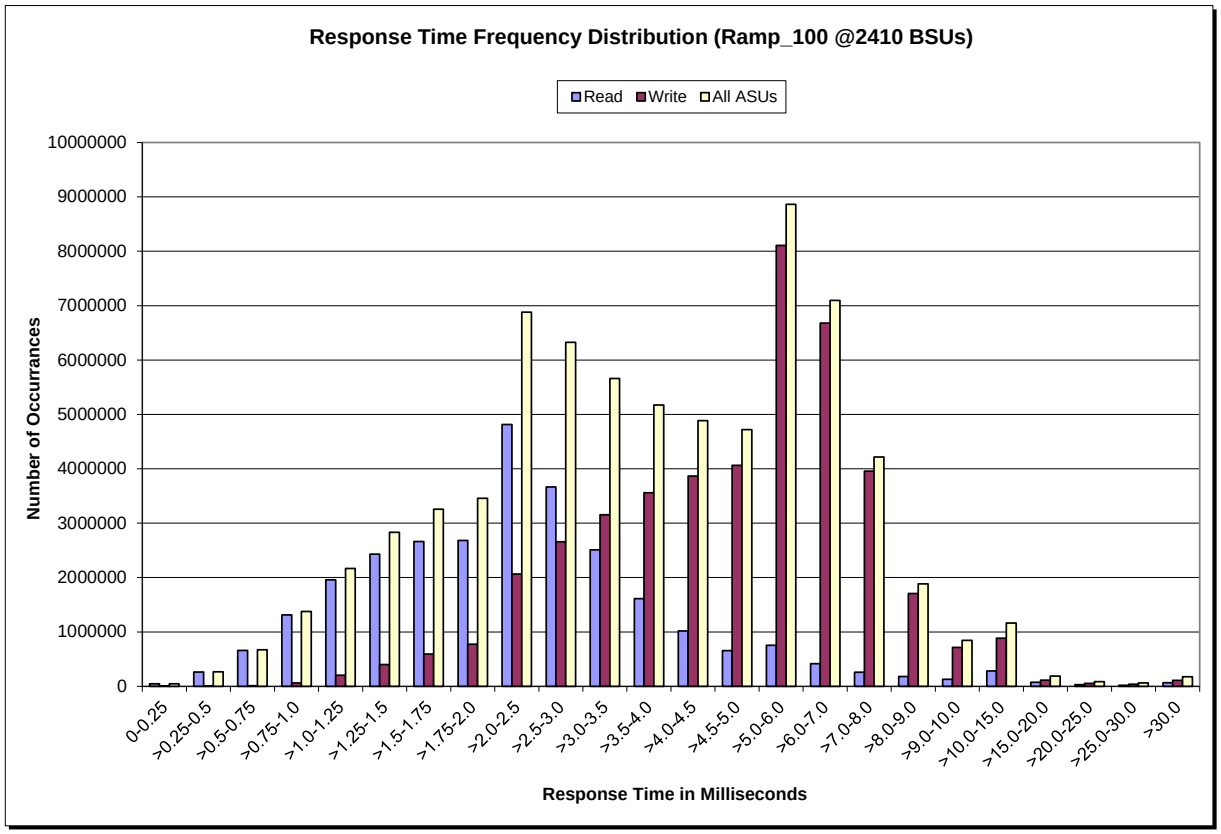
IOPS Test Run – Average Response Time (ms) Distribution Graph



IOPS Test Run – Response Time Frequency Distribution Data

Response Time (ms)	0-0.25	>0.25-0.5	>0.5-0.75	>0.75-1.0	>1.0-1.25	>1.25-1.5	>1.5-1.75	>1.75-2.0
Read	46,068	261,490	658,540	1,312,935	1,960,002	2,431,226	2,664,632	2,681,031
Write	65	4,255	12,109	61,721	205,306	399,085	591,611	775,873
All ASUs	46,133	265,745	670,649	1,374,656	2,165,308	2,830,311	3,256,243	3,456,904
ASU1	43,695	243,619	588,170	1,166,155	1,780,010	2,263,180	2,542,573	2,631,975
ASU2	2,423	20,499	77,823	185,634	306,368	407,009	470,569	500,616
ASU3	15	1,627	4,656	22,867	78,930	160,122	243,101	324,313
Response Time (ms)	**>2.0-2.5**	**>2.5-3.0**	**>3.0-3.5**	**>3.5-4.0**	**>4.0-4.5**	**>4.5-5.0**	**>5.0-6.0**	**>6.0-7.0**
Read	4,814,004	3,667,348	2,509,096	1,613,415	1,017,246	654,358	755,018	415,089
Write	2,064,531	2,660,107	3,153,406	3,559,812	3,867,967	4,064,550	8,109,616	6,680,987
All ASUs	6,878,535	6,327,455	5,662,502	5,173,227	4,885,213	4,718,908	8,864,634	7,096,076
ASU1	5,015,645	4,304,033	3,541,343	2,968,934	2,603,517	2,379,443	4,248,345	3,234,198
ASU2	986,433	881,753	756,330	655,224	588,546	545,642	981,523	748,291
ASU3	876,457	1,141,669	1,364,829	1,549,069	1,693,150	1,793,823	3,634,766	3,113,587
Response Time (ms)	**>7.0-8.0**	**>8.0-9.0**	**>9.0-10.0**	**>10.0-15.0**	**>15.0-20.0**	**>20.0-25.0**	**>25.0-30.0**	**>30.0**
Read	260,602	179,924	129,600	282,931	73,930	31,523	20,596	66,948
Write	3,957,353	1,704,934	714,387	882,478	114,829	52,658	39,753	109,837
All ASUs	4,217,955	1,884,858	843,987	1,165,409	188,759	84,181	60,349	176,785
ASU1	1,793,274	713,327	281,297	458,807	104,721	47,896	33,823	100,256
ASU2	410,515	156,908	58,001	93,123	21,769	10,136	7,133	20,166
ASU3	2,014,166	1,014,623	504,689	613,479	62,269	26,149	19,393	56,363

IOPS Test Run –Response Time Frequency Distribution Graph



IOPS Test Run – I/O Request Information

I/O Requests Completed in the Measurement Interval	I/O Requests Completed with Response Time = or < 30 ms	I/O Requests Completed with Response Time > 30 ms
72,294,782	72,117,997	176,785

IOPS Test Run – Measured Intensity Multiplier and Coefficient of Variation

Clause 3.4.3

IM – Intensity Multiplier: *The ratio of I/Os for each I/O stream relative to the total I/Os for all I/O streams (ASU1-1 – ASU3-1) as required by the benchmark specification.*

Clauses 5.1.10 and 5.3.13.2

MIM – Measured Intensity Multiplier: *The Measured Intensity Multiplier represents the ratio of measured I/Os for each I/O stream relative to the total I/Os measured for all I/O streams (ASU1-1 – ASU3-1). This value may differ from the corresponding Expected Intensity Multiplier by no more than 5%.*

Clause 5.3.13.3

COV – Coefficient of Variation: *This measure of variation for the Measured Intensity Multiplier cannot exceed 0.2.*

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2810	0.0700	0.2100	0.0180	0.0700	0.0350	0.2810
COV	0.002	0.001	0.001	0.001	0.002	0.002	0.002	0.000

Primary Metrics Test – Response Time Ramp Test Phase

Clause 5.4.4.3

The Response Time Ramp Test Phase consists of five Test Runs, one each at 95%, 90%, 80%, 50%, and 10% of the load point (100%) used to generate the SPC-1 IOPS™ primary metric. Each of the five Test Runs has a Measurement Interval of ten (10) minutes. The Response Time Ramp Test Phase immediately follows the IOPS Test Phase without any interruption or manual intervention.

The five Response Time Ramp Test Runs, in conjunction with the IOPS Test Run (100%), demonstrate the relationship between Average Response Time and I/O Request Throughput for the Tested Storage Configuration (TSC) as illustrated in the response time/throughput curve on page 14.

In addition, the Average Response Time measured during the 10% Test Run is the value for the SPC-1 LRT™ metric. That value represents the Average Response Time of a lightly loaded TSC.

Clause 9.4.3.7.3

The following content shall appear in the FDR for the Response Time Ramp Phase:

1. *A Response Time Ramp Distribution.*
2. *The human readable Test Run Results File produced by the Workload Generator for each Test Run within the Response Time Ramp Test Phase.*
3. *For the 10% Load Level Test Run (SPC-1 LRT™ metric) an Average Response Time Distribution.*
4. *A listing or screen image of all input parameters supplied to the Workload Generator.*

SPC-1 Workload Generator Input Parameters

The SPC-1 Workload Generator input parameters for the Sustainability, IOPS, Response Time Ramp, Repeatability, and Persistence Test Runs are documented in "Appendix E: SPC-1 Workload Generator Input Parameters" on Page 66.

Response Time Ramp Test Results File

A link to each test result file generated from each Response Time Ramp Test Run list listed below.

95% Load Level

90% Load Level

80% Load Level

50% Load Level

10% Load Level

Response Time Ramp Distribution (IOPS) Data

The five Test Runs that comprise the Response Time Ramp Phase are executed at 95%, 90%, 80%, 50%, and 10% of the Business Scaling Unit (BSU) load level used to produce the SPC-1 IOPS™ primary metric. The 100% BSU load level is included in the following Response Time Ramp data tables and graphs for completeness.

100% Load Level - 2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	16:56:03	16:59:04	0-2	0:03:01
Measurement Interval	16:59:04	17:09:04	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	120,628.12	71,897.92	14,823.10	33,907.10
1	120,515.15	71,799.53	14,830.37	33,885.25
2	120,552.57	71,858.52	14,843.68	33,850.37
3	120,453.38	71,782.45	14,799.10	33,871.83
4	120,483.77	71,801.73	14,832.20	33,849.83
5	120,546.50	71,840.53	14,833.58	33,872.38
6	120,467.65	71,817.58	14,819.32	33,830.75
7	120,408.30	71,762.67	14,806.52	33,839.12
8	120,519.63	71,853.18	14,815.80	33,850.65
9	120,477.18	71,776.35	14,861.93	33,838.90
10	120,570.92	71,862.07	14,824.12	33,884.73
11	120,508.22	71,807.55	14,816.97	33,883.70
12	120,487.88	71,838.62	14,799.02	33,850.25
Average	***120,492.34***	***71,814.27***	***14,820.86***	***33,857.22***

95% Load Level - 2,289 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	17:09:25	17:12:26	0-2	0:03:01
Measurement Interval	17:12:26	17:22:26	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	114,624.80	68,327.45	14,098.12	32,199.23
1	114,449.58	68,190.17	14,059.27	32,200.15
2	114,370.37	68,208.62	14,062.85	32,098.90
3	114,447.17	68,163.70	14,109.28	32,174.18
4	114,434.33	68,205.07	14,057.80	32,171.47
5	114,445.23	68,276.85	14,064.10	32,104.28
6	114,483.72	68,244.03	14,067.73	32,171.95
7	114,343.10	68,194.05	14,051.77	32,097.28
8	114,482.85	68,214.62	14,075.45	32,192.78
9	114,402.52	68,179.70	14,072.67	32,150.15
10	114,460.47	68,199.70	14,067.83	32,192.93
11	114,392.82	68,197.93	14,073.45	32,121.43
12	114,412.53	68,210.75	14,082.25	32,119.53
Average	***114,430.47***	***68,208.64***	***14,072.23***	***32,149.60***

90% Load Level - 2,169 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	17:22:45	17:25:46	0-2	0:03:01
Measurement Interval	17:25:46	17:35:46	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	108,508.28	64,683.47	13,345.48	30,479.33
1	108,461.33	64,653.48	13,343.43	30,464.42
2	108,483.63	64,674.35	13,338.53	30,470.75
3	108,483.97	64,657.77	13,347.05	30,479.15
4	108,433.98	64,628.55	13,339.38	30,466.05
5	108,432.75	64,613.72	13,337.73	30,481.30
6	108,431.70	64,645.03	13,343.28	30,443.38
7	108,398.95	64,571.18	13,353.48	30,474.28
8	108,422.38	64,614.18	13,339.00	30,469.20
9	108,557.38	64,724.42	13,334.00	30,498.97
10	108,417.47	64,626.30	13,345.23	30,445.93
11	108,421.50	64,621.33	13,332.57	30,467.60
12	108,422.38	64,651.23	13,320.18	30,450.97
Average	***108,442.25***	***64,635.37***	***13,339.19***	***30,467.68***

80% Load Level - 1,928 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	17:36:03	17:39:04	0-2	0:03:01
Measurement Interval	17:39:04	17:49:04	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	96,482.23	57,488.07	11,864.28	27,129.88
1	96,399.13	57,467.38	11,839.88	27,091.87
2	96,371.02	57,441.75	11,862.97	27,066.30
3	96,380.02	57,433.73	11,846.85	27,099.43
4	96,461.17	57,490.18	11,863.15	27,107.83
5	96,370.42	57,440.17	11,866.60	27,063.65
6	96,419.12	57,448.52	11,883.45	27,087.15
7	96,372.88	57,436.23	11,843.30	27,093.35
8	96,383.28	57,456.15	11,860.08	27,067.05
9	96,412.87	57,446.80	11,865.83	27,100.23
10	96,428.38	57,490.17	11,843.63	27,094.58
11	96,411.12	57,458.20	11,892.28	27,060.63
12	96,424.30	57,469.23	11,847.10	27,107.97
Average	***96,406.36***	***57,456.94***	***11,861.23***	***27,088.19***

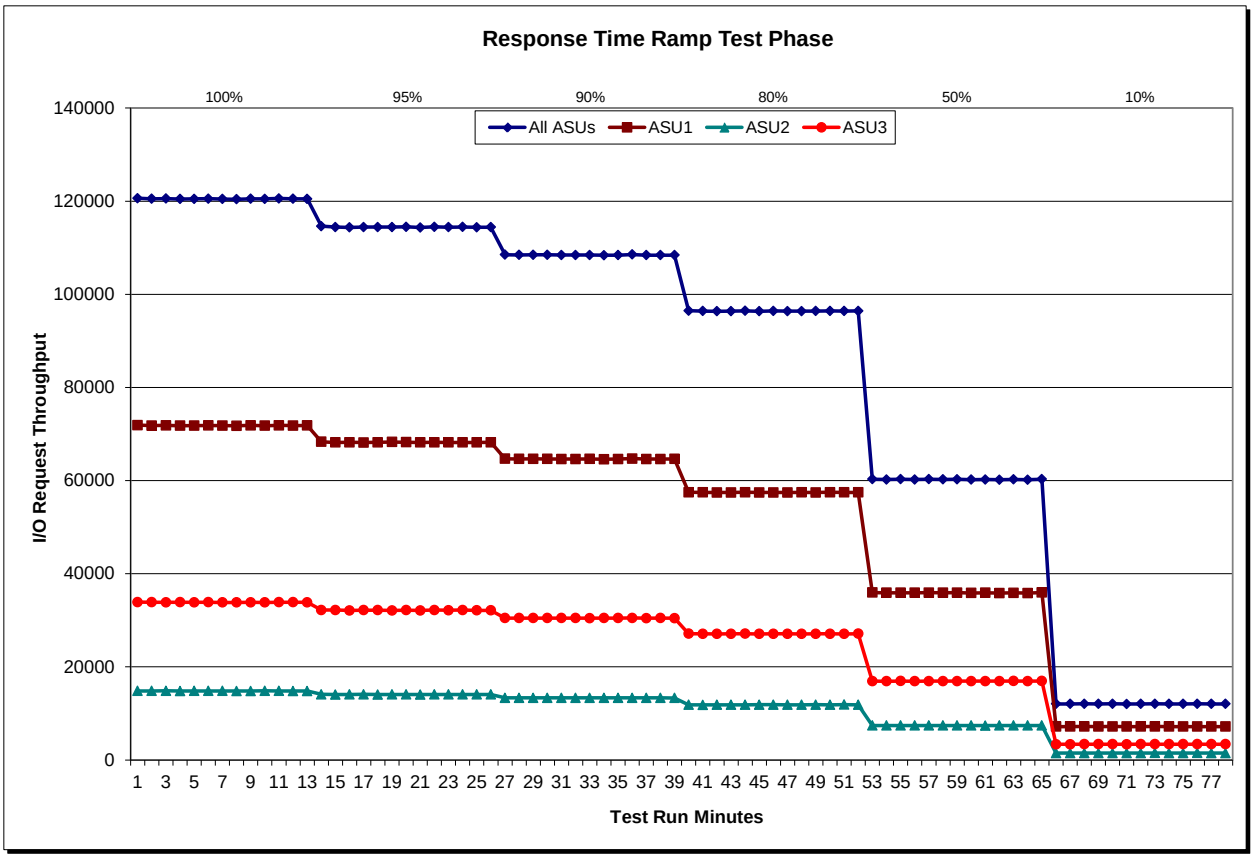
50% Load Level - 1,205 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	17:49:20	17:52:21	0-2	0:03:01
Measurement Interval	17:52:21	18:02:21	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	60,303.17	35,959.20	7,418.30	16,925.67
1	60,238.68	35,902.17	7,418.98	16,917.53
2	60,290.58	35,914.68	7,418.97	16,956.93
3	60,219.57	35,901.68	7,417.67	16,900.22
4	60,289.83	35,941.33	7,413.50	16,935.00
5	60,256.70	35,916.10	7,410.85	16,929.75
6	60,284.42	35,932.98	7,416.22	16,935.22
7	60,203.55	35,864.43	7,398.82	16,940.30
8	60,229.20	35,905.08	7,397.18	16,926.93
9	60,185.45	35,843.97	7,406.58	16,934.90
10	60,244.50	35,888.38	7,400.97	16,955.15
11	60,191.48	35,844.40	7,411.97	16,935.12
12	60,300.90	35,947.00	7,407.15	16,946.75
Average	***60,240.56***	***35,898.54***	***7,408.09***	***16,933.93***

10% Load Level - 241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:02:33	18:05:34	0-2	0:03:01
Measurement Interval	18:05:34	18:15:34	3-12	0:10:00

(60 second intervals)	All ASUs	ASU-1	ASU-2	ASU-3
0	12,032.15	7,182.85	1,473.20	3,376.10
1	12,048.22	7,185.68	1,482.05	3,380.48
2	12,064.35	7,194.72	1,479.65	3,389.98
3	12,039.27	7,169.82	1,488.22	3,381.23
4	12,066.35	7,190.10	1,483.02	3,393.23
5	12,028.90	7,174.88	1,475.97	3,378.05
6	12,046.78	7,179.33	1,475.60	3,391.85
7	12,076.38	7,190.05	1,492.30	3,394.03
8	12,044.67	7,181.00	1,478.02	3,385.65
9	12,040.95	7,176.87	1,476.90	3,387.18
10	12,068.68	7,184.97	1,490.73	3,392.98
11	12,043.00	7,174.68	1,483.43	3,384.88
12	12,034.65	7,163.60	1,483.82	3,387.23
Average	***12,048.96***	***7,178.53***	***1,482.80***	***3,387.63***

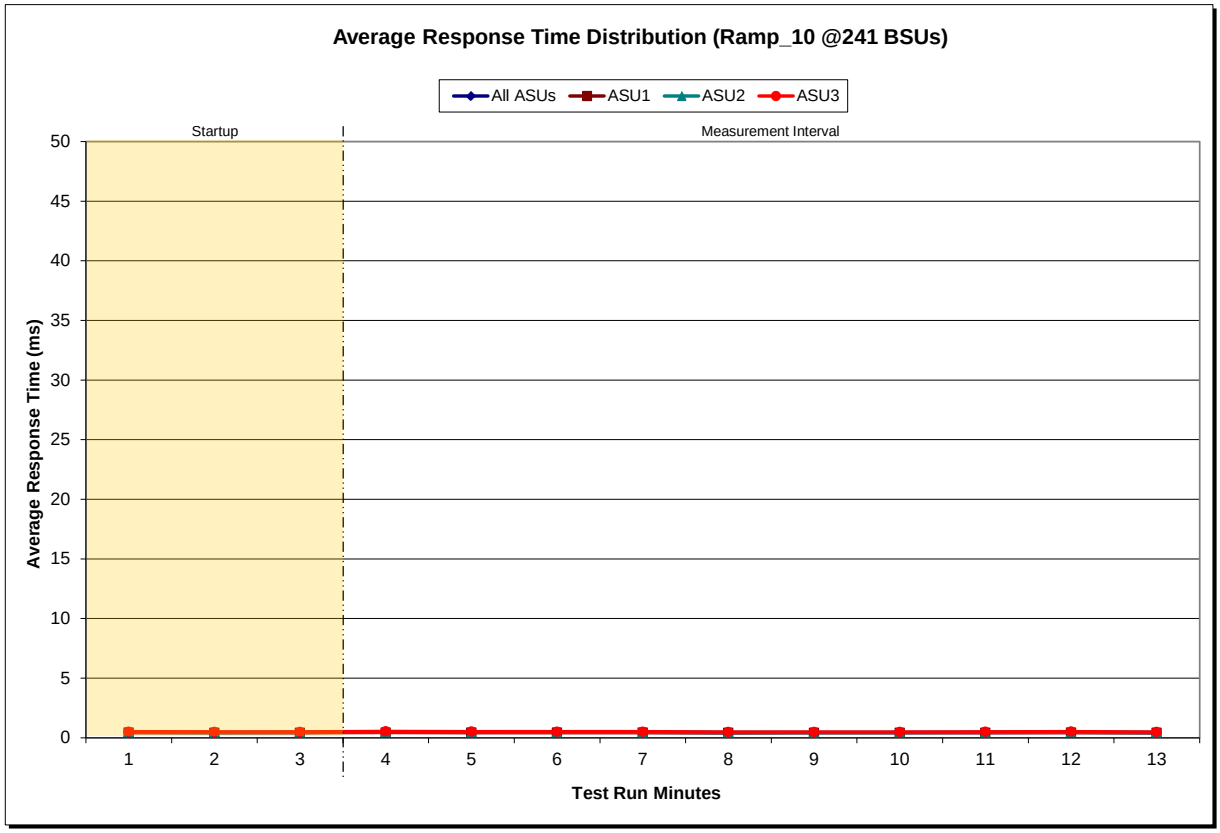
Response Time Ramp Distribution (IOPS) Graph



SPC-1 LRT™ Average Response Time (ms) Distribution Data

241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:02:33	18:05:34	0-2	0:03:01
Measurement Interval	18:05:34	18:15:34	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	0.45	0.43	0.46	0.50
1	0.44	0.42	0.45	0.49
2	0.44	0.41	0.45	0.49
3	0.47	0.44	0.48	0.53
4	0.46	0.43	0.47	0.52
5	0.45	0.42	0.46	0.50
6	0.45	0.42	0.46	0.51
7	0.43	0.41	0.44	0.48
8	0.44	0.42	0.45	0.48
9	0.44	0.41	0.45	0.48
10	0.44	0.42	0.45	0.49
11	0.45	0.42	0.46	0.52
12	0.44	0.41	0.44	0.48
Average	***0.45***	***0.42***	***0.46***	***0.50***

SPC-1 LRT™ Average Response Time (ms) Distribution Graph



SPC-1 LRT™ (10%) – Measured Intensity Multiplier and Coefficient of Variation

Clause 3.4.3

IM – Intensity Multiplier: *The ratio of I/Os for each I/O stream relative to the total I/Os for all I/O streams (ASU1-1 – ASU3-1) as required by the benchmark specification.*

Clauses 5.1.10 and 5.3.13.2

MIM – Measured Intensity Multiplier: *The Measured Intensity Multiplier represents the ratio of measured I/Os for each I/O stream relative to the total I/Os measured for all I/O streams (ASU1-1 – ASU3-1). This value may differ from the corresponding Expected Intensity Multiplier by no more than 5%.*

Clause 5.3.13.3

COV – Coefficient of Variation: *This measure of variation for the Measured Intensity Multiplier cannot exceed 0.2.*

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2809	0.0700	0.2099	0.0180	0.0700	0.0351	0.2812
COV	0.006	0.002	0.005	0.002	0.009	0.004	0.009	0.001

Repeatability Test

Clause 5.4.5

The Repeatability Test demonstrates the repeatability and reproducibility of the SPC-1 IOPS™ primary metric and the SPC-1 LRT™ metric generated in earlier Test Runs.

There are two identical Repeatability Test Phases. Each Test Phase contains two Test Runs. Each of the Test Runs will have a Measurement Interval of no less than ten (10) minutes. The two Test Runs in each Test Phase will be executed without interruption or any type of manual intervention.

The first Test Run in each Test Phase is executed at the 10% load point. The Average Response Time from each of the Test Runs is compared to the SPC-1 LRT™ metric. Each Average Response Time value must be less than the SPC-1 LRT™ metric plus 5% or less than the SPC-1 LRT™ metric plus one (1) millisecond (ms).

The second Test Run in each Test Phase is executed at the 100% load point. The I/O Request Throughput from the Test Runs is compared to the SPC-1 IOPS™ primary metric. Each I/O Request Throughput value must be greater than the SPC-1 IOPS™ primary metric minus 5%. In addition, the Average Response Time for each Test Run cannot exceed 30 milliseconds.

If any of the above constraints are not met, the benchmark measurement is invalid.

Clause 9.4.3.7.4

The following content shall appear in the FDR for each Test Run in the two Repeatability Test Phases:

1. *A table containing the results of the Repeatability Test.*
2. *An I/O Request Throughput Distribution graph and table.*
3. *An Average Response Time Distribution graph and table.*
4. *The human readable Test Run Results File produced by the Workload Generator.*
5. *A listing or screen image of all input parameters supplied to the Workload Generator.*

SPC-1 Workload Generator Input Parameters

The SPC-1 Workload Generator input parameters for the Sustainability, IOPS, Response Time Ramp, Repeatability, and Persistence Test Runs are documented in "Appendix E: SPC-1 Workload Generator Input Parameters" on Page 66.

Repeatability Test Results File

The values for the SPC-1 IOPS™, SPC-1 LRT™, and the Repeatability Test measurements are listed in the tables below.

	SPC-1 IOPS™
Primary Metrics	***120,492.34***
Repeatability Test Phase 1	120,482.83
Repeatability Test Phase 2	120,501.21

The SPC-1 IOPS™ values in the above table were generated using 100% of the specified Business Scaling Unit (BSU) load level. Each of the Repeatability Test Phase values for SPC-1 IOPS™ must greater than 95% of the reported SPC-1 IOPS™ Primary Metric.

	SPC-1 LRT™
Primary Metrics	***0.45 ms***
Repeatability Test Phase 1	0.44 ms
Repeatability Test Phase 2	0.44 ms

The average response time values in the SPC-1 LRT™ column were generated using 10% of the specified Business Scaling Unit (BSU) load level. Each of the Repeatability Test Phase values for SPC-1 LRT™ must be less than 105% of the reported SPC-1 LRT™ Primary Metric or less than the reported SPC-1 LRT™ Primary Metric minus one (1) millisecond (ms)...

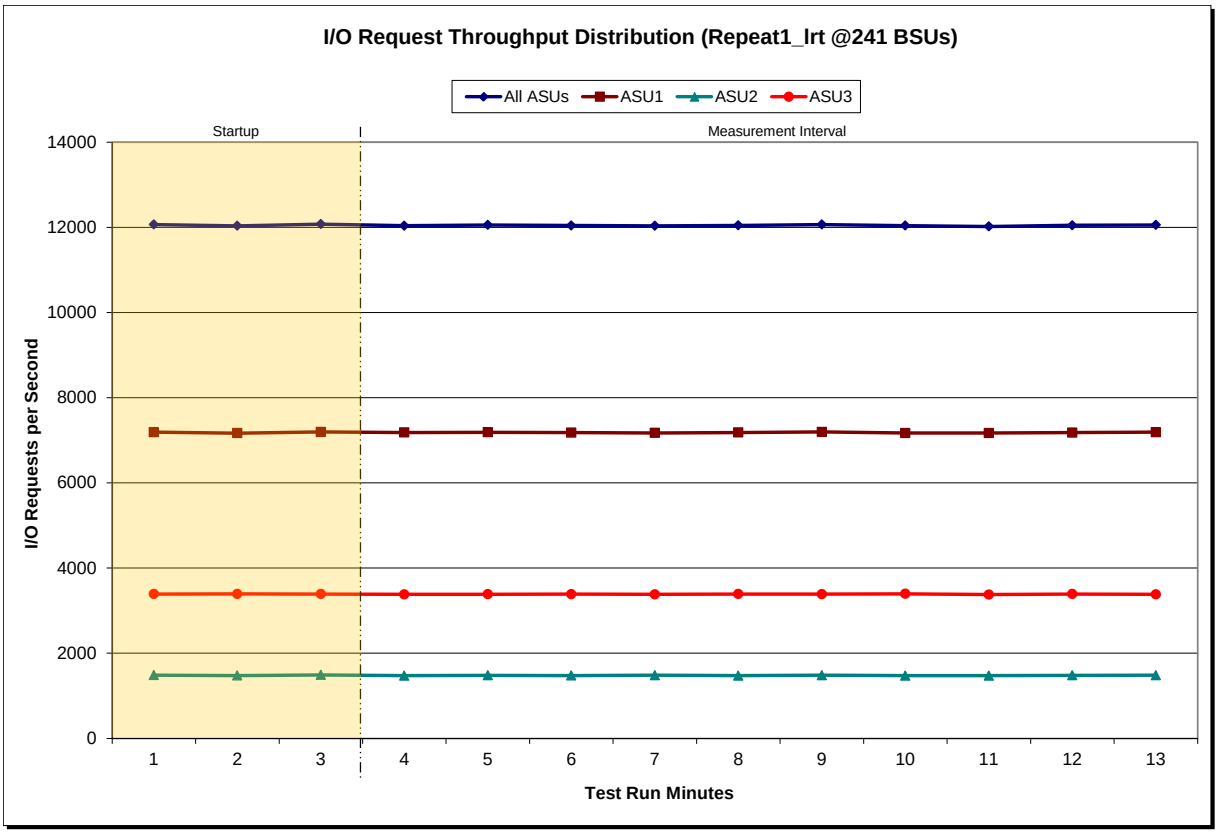
A link to the test result file generated from each Repeatability Test Run is listed below.

Repeatability Test Phase 1, Test Run 1 (LRT)
Repeatability Test Phase 1, Test Run 2 (IOPS)
Repeatability Test Phase 2, Test Run 1 (LRT)
Repeatability Test Phase 2, Test Run 2 (IOPS)

Repeatability 1 LRT – I/O Request Throughput Distribution Data

241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:16:30	18:19:30	0-2	0:03:00
Measurement Interval	18:19:30	18:29:30	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	12,068.68	7,191.57	1,485.62	3,391.50
1	12,038.30	7,169.13	1,477.30	3,391.87
2	12,077.00	7,196.10	1,490.93	3,389.97
3	12,039.13	7,183.43	1,472.98	3,382.72
4	12,057.60	7,189.98	1,481.63	3,385.98
5	12,044.43	7,180.90	1,475.83	3,387.70
6	12,038.48	7,173.63	1,483.15	3,381.70
7	12,048.02	7,183.38	1,473.02	3,391.62
8	12,068.08	7,195.97	1,483.88	3,388.23
9	12,041.18	7,170.60	1,474.08	3,396.50
10	12,023.33	7,172.02	1,474.72	3,376.60
11	12,051.03	7,180.23	1,480.73	3,390.07
12	12,056.97	7,190.22	1,483.05	3,383.70
Average	***12,046.83***	***7,182.04***	***1,478.31***	***3,386.48***

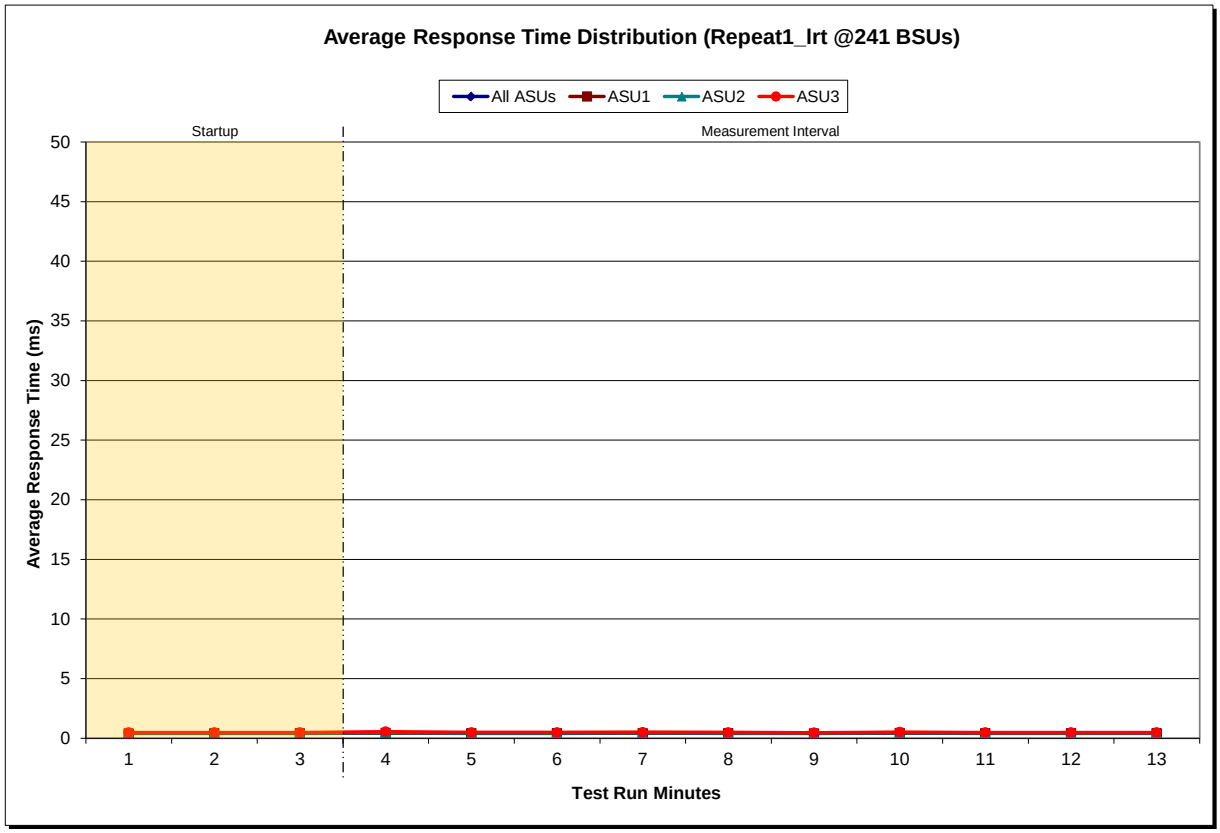
Repeatability 1 LRT – I/O Request Throughput Distribution Graph



Repeatability 1 LRT –Average Response Time (ms) Distribution Data

241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:16:30	18:19:30	0-2	0:03:00
Measurement Interval	18:19:30	18:29:30	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	0.43	0.40	0.44	0.48
1	0.43	0.41	0.44	0.48
2	0.44	0.41	0.45	0.48
3	0.47	0.43	0.47	0.55
4	0.44	0.41	0.44	0.49
5	0.44	0.41	0.45	0.49
6	0.45	0.42	0.46	0.51
7	0.43	0.41	0.45	0.49
8	0.42	0.40	0.43	0.46
9	0.45	0.42	0.46	0.51
10	0.43	0.41	0.44	0.48
11	0.44	0.41	0.44	0.49
12	0.43	0.41	0.44	0.48
Average	***0.44***	***0.41***	***0.45***	***0.49***

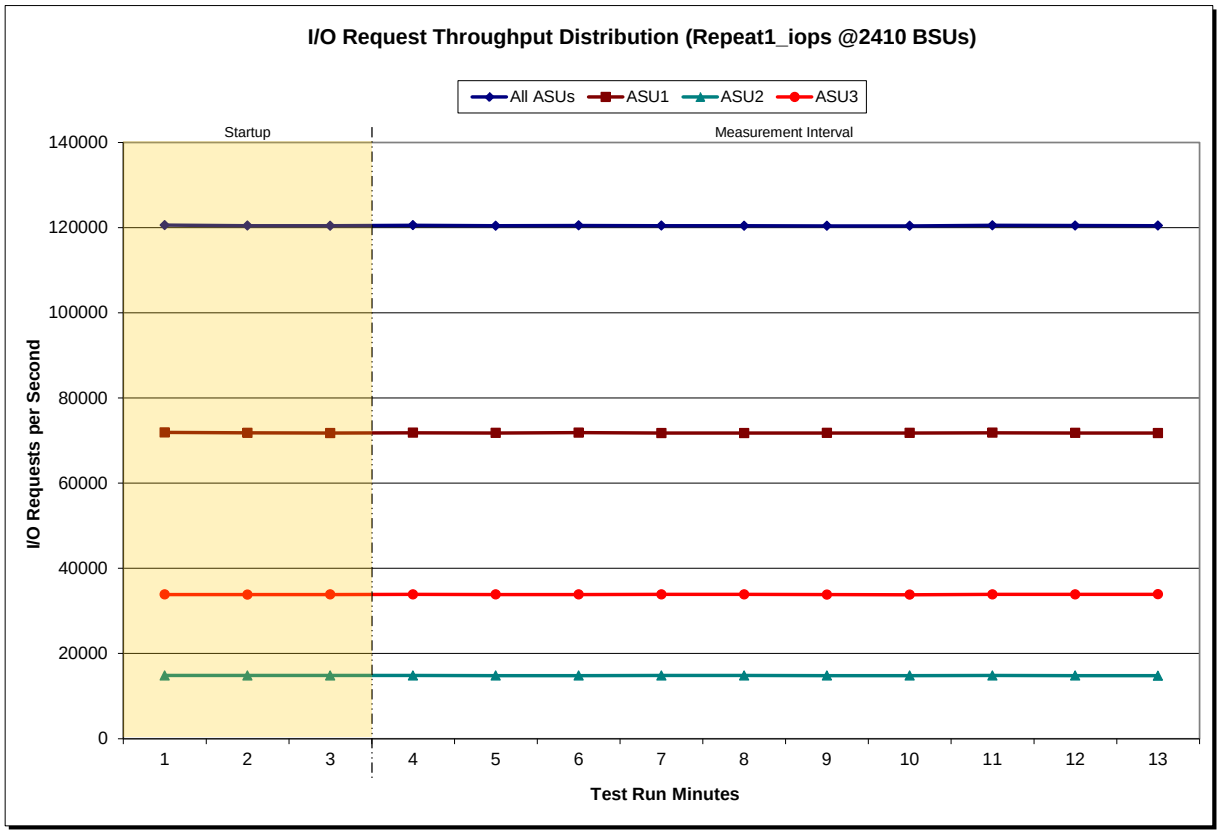
Repeatability 1 LRT –Average Response Time (ms) Distribution Graph



Repeatability 1 IOPS – I/O Request Throughput Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:29:52	18:32:53	0-2	0:03:01
Measurement Interval	18:32:53	18:42:53	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	120,591.95	71,903.75	14,839.30	33,848.90
1	120,473.75	71,803.63	14,841.52	33,828.60
2	120,448.97	71,764.18	14,829.73	33,855.05
3	120,567.62	71,848.75	14,833.37	33,885.50
4	120,455.33	71,794.90	14,807.27	33,853.17
5	120,520.13	71,855.55	14,808.83	33,855.75
6	120,468.82	71,752.70	14,827.83	33,888.28
7	120,461.07	71,750.42	14,832.77	33,877.88
8	120,418.02	71,784.13	14,806.45	33,827.43
9	120,416.22	71,785.30	14,816.33	33,814.58
10	120,550.03	71,836.37	14,834.35	33,879.32
11	120,505.80	71,795.33	14,821.65	33,888.82
12	120,465.22	71,769.70	14,793.58	33,901.93
Average	***120,482.83***	***71,797.32***	***14,818.24***	***33,867.27***

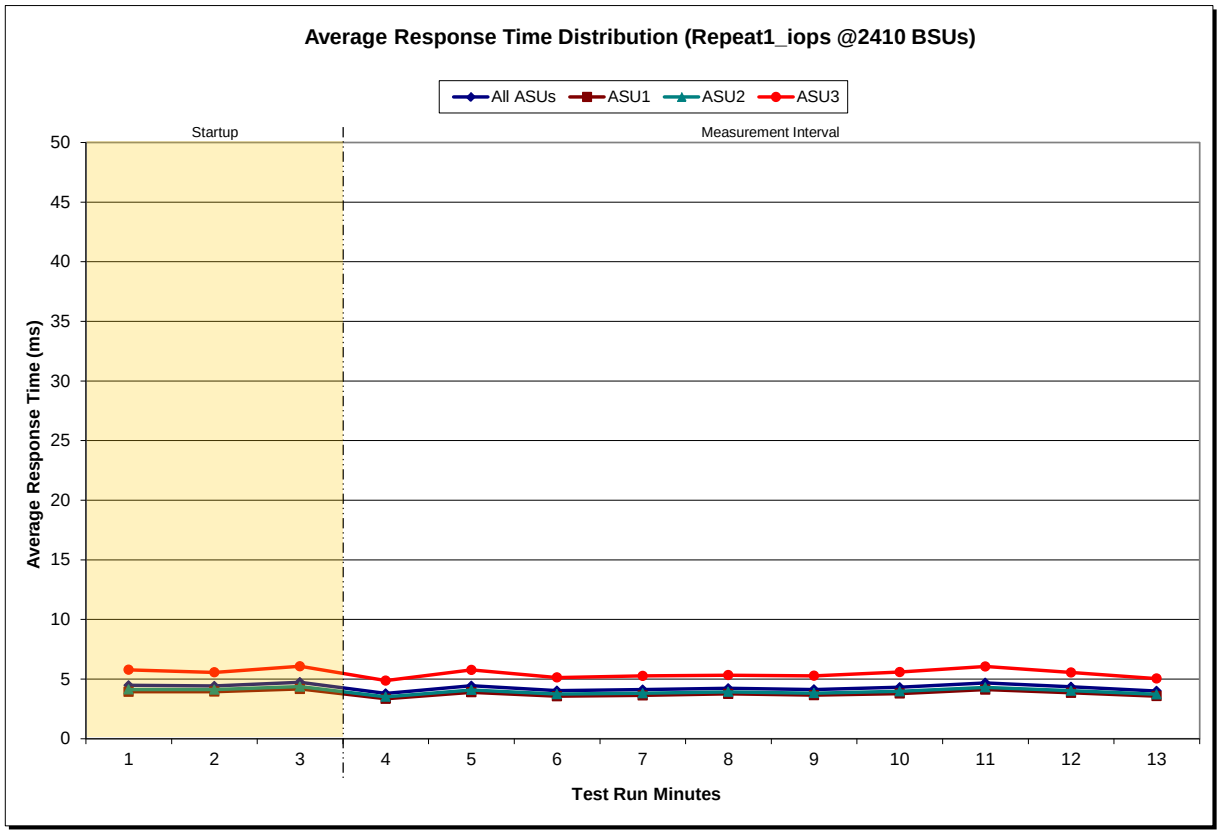
Repeatability 1 IOPS – I/O Request Throughput Distribution Graph



Repeatability 1 IOPS –Average Response Time (ms) Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:29:52	18:32:53	0-2	0:03:01
Measurement Interval	18:32:53	18:42:53	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	4.47	3.93	4.12	5.77
1	4.42	3.95	4.11	5.56
2	4.73	4.17	4.37	6.07
3	3.79	3.34	3.51	4.87
4	4.44	3.89	4.09	5.77
5	4.02	3.56	3.73	5.13
6	4.11	3.63	3.81	5.26
7	4.22	3.76	3.93	5.33
8	4.12	3.65	3.82	5.27
9	4.31	3.78	3.97	5.59
10	4.68	4.11	4.31	6.05
11	4.34	3.84	4.02	5.55
12	4.00	3.57	3.72	5.04
Average	***4.21***	***3.71***	***3.89***	***5.39***

Repeatability 1 IOPS –Average Response Time (ms) Distribution Graph

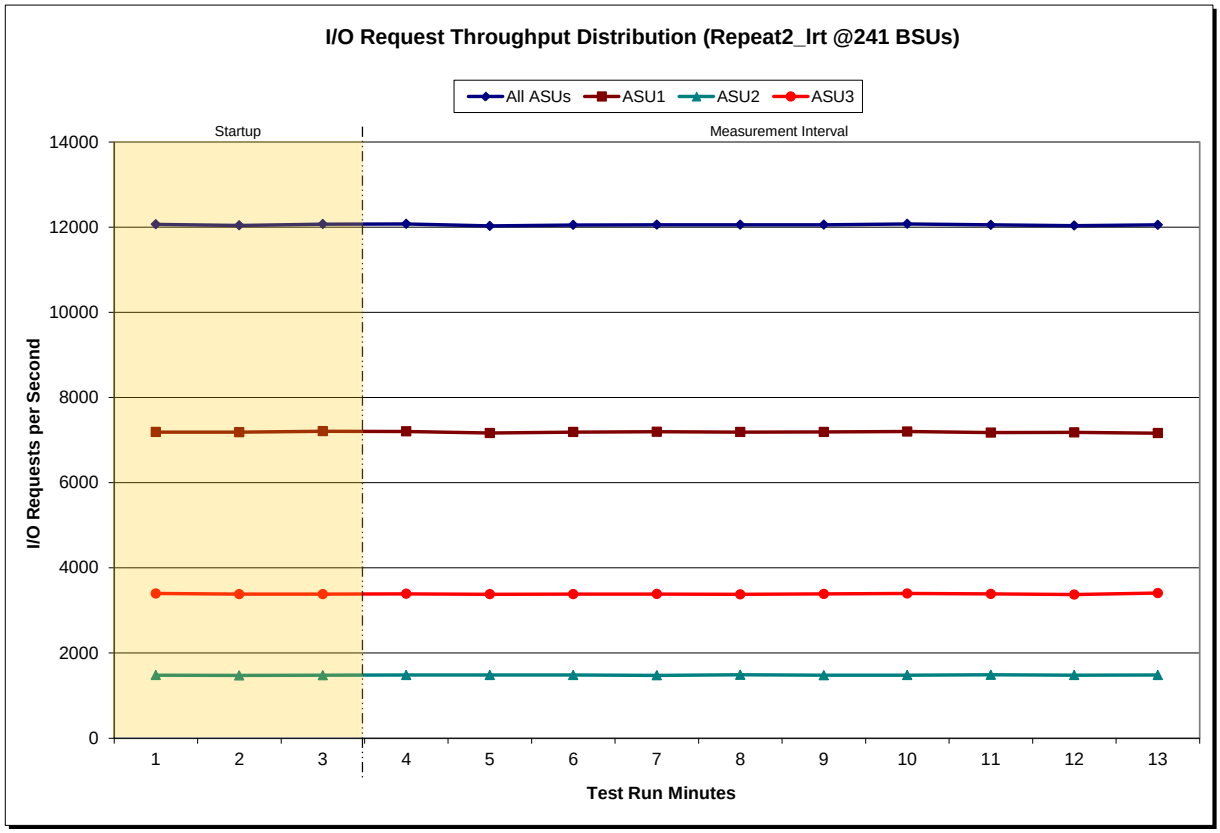


Repeatability 2 LRT – I/O Request Throughput Distribution Data

241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:43:43	18:46:43	0-2	0:03:00
Measurement Interval	18:46:43	18:56:43	3-12	0:10:00

60 second intervals	All ASUs	ASU1	ASU2	ASU3
0	12,067.53	7,187.60	1,482.25	3,397.68
1	12,043.15	7,186.38	1,474.32	3,382.45
2	12,072.45	7,209.92	1,478.53	3,384.00
3	12,076.90	7,203.57	1,482.82	3,390.52
4	12,029.97	7,165.78	1,484.18	3,380.00
5	12,053.48	7,188.20	1,482.77	3,382.52
6	12,057.22	7,195.23	1,475.42	3,386.57
7	12,056.27	7,189.57	1,489.20	3,377.50
8	12,057.27	7,192.17	1,478.35	3,386.75
9	12,078.60	7,201.43	1,480.38	3,396.78
10	12,054.18	7,176.62	1,489.10	3,388.47
11	12,036.87	7,181.02	1,482.12	3,373.73
12	12,055.73	7,162.58	1,484.62	3,408.53
Average	***12,055.65***	***7,185.62***	***1,482.90***	***3,387.14***

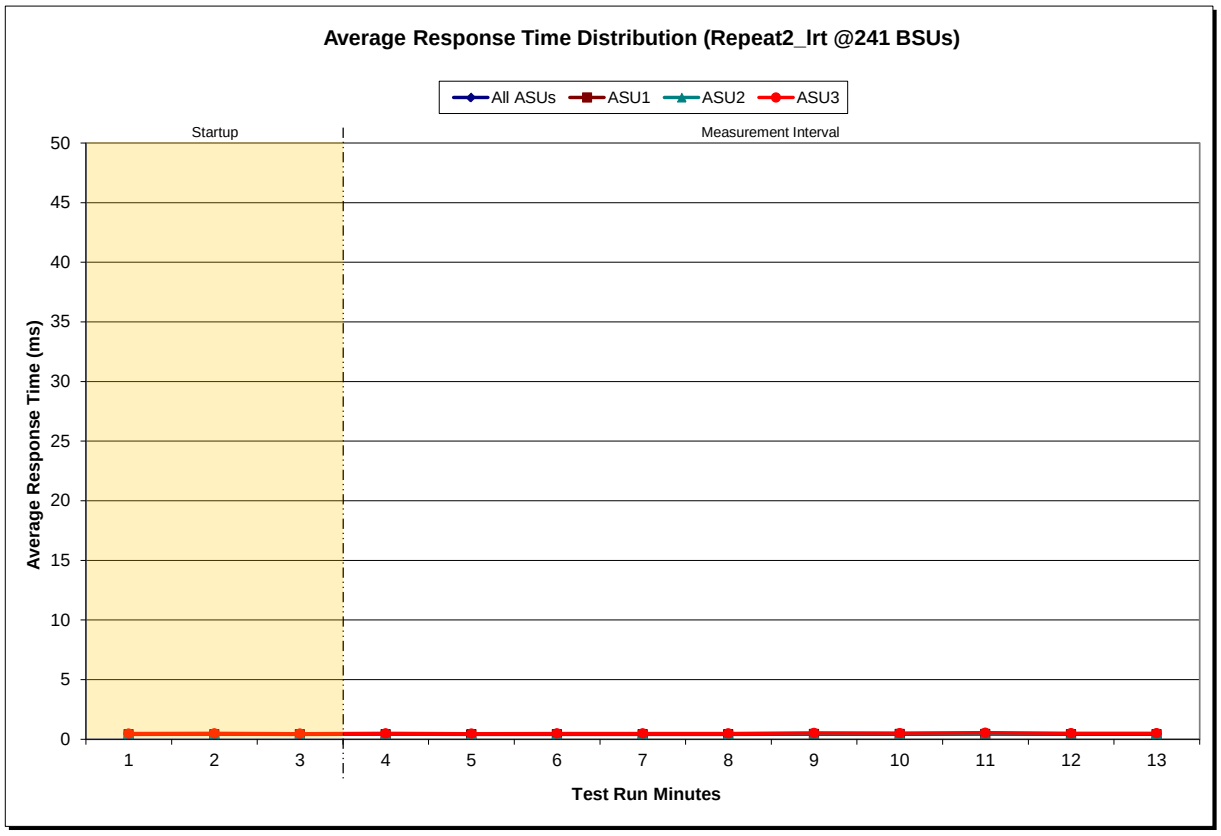
Repeatability 2 LRT – I/O Request Throughput Distribution Graph



Repeatability 2 LRT –Average Response Time (ms) Distribution Data

241 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:43:43	18:46:43	0-2	0:03:00
Measurement Interval	18:46:43	18:56:43	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	0.43	0.41	0.44	0.47
1	0.44	0.41	0.44	0.49
2	0.43	0.41	0.44	0.46
3	0.44	0.41	0.45	0.49
4	0.43	0.40	0.44	0.47
5	0.43	0.41	0.45	0.48
6	0.43	0.41	0.44	0.48
7	0.43	0.41	0.44	0.48
8	0.46	0.43	0.47	0.52
9	0.45	0.42	0.45	0.50
10	0.47	0.43	0.47	0.54
11	0.45	0.42	0.46	0.50
12	0.45	0.42	0.45	0.50
Average	***0.44***	***0.42***	***0.45***	***0.50***

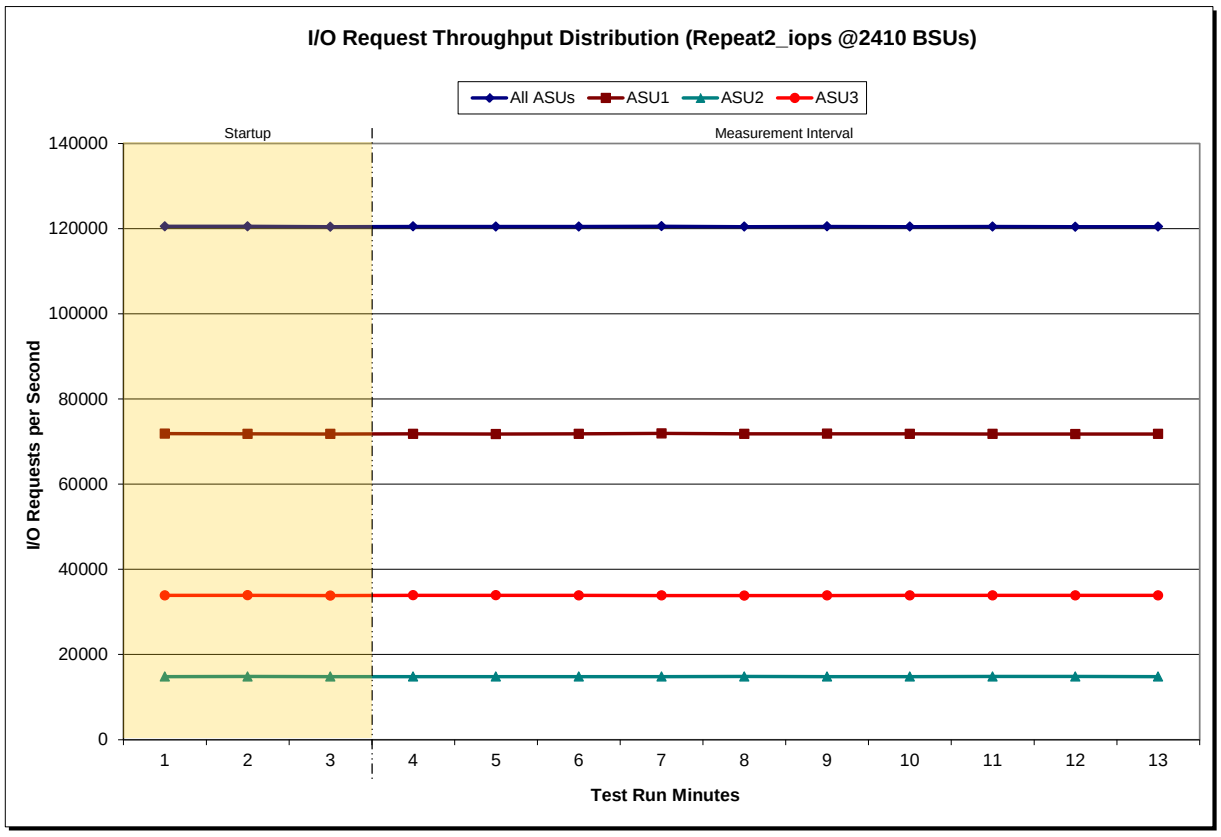
Repeatability 2 LRT –Average Response Time (ms) Distribution Graph



Repeatability 2 IOPS – I/O Request Throughput Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:57:04	19:00:05	0-2	0:03:01
Measurement Interval	19:00:05	19:10:05	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	120,553.88	71,870.23	14,808.65	33,875.00
1	120,559.27	71,813.97	14,840.58	33,904.72
2	120,450.55	71,797.80	14,819.93	33,832.82
3	120,531.37	71,823.37	14,814.67	33,893.33
4	120,487.20	71,773.83	14,817.72	33,895.65
5	120,499.05	71,812.92	14,816.98	33,869.15
6	120,586.85	71,908.62	14,822.65	33,855.58
7	120,477.50	71,819.55	14,827.13	33,830.82
8	120,513.33	71,834.98	14,822.63	33,855.72
9	120,482.73	71,806.57	14,802.58	33,873.58
10	120,501.07	71,780.70	14,842.20	33,878.17
11	120,452.82	71,754.65	14,831.27	33,866.90
12	120,480.20	71,789.28	14,821.05	33,869.87
Average	***120,501.21***	***71,810.45***	***14,821.89***	***33,868.88***

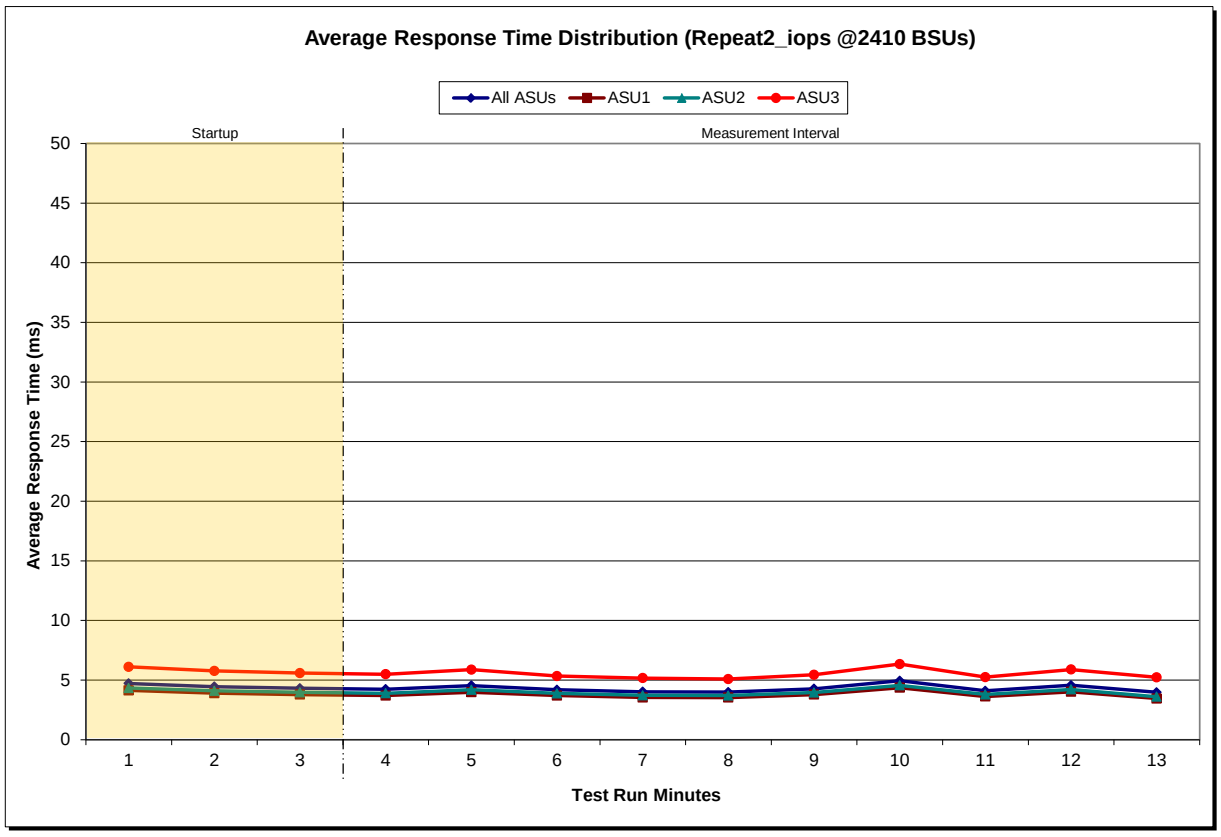
Repeatability 2 IOPS – I/O Request Throughput Distribution Graph



Repeatability 2 IOPS –Average Response Time (ms) Distribution Data

2,410 BSUs	Start	Stop	Interval	Duration
Start-Up/Ramp-Up	18:57:04	19:00:05	0-2	0:03:01
Measurement Interval	19:00:05	19:10:05	3-12	0:10:00
60 second intervals	**All ASUs**	**ASU1**	**ASU2**	**ASU3**
0	4.71	4.13	4.33	6.11
1	4.45	3.90	4.09	5.76
2	4.31	3.78	3.98	5.58
3	4.23	3.70	3.89	5.49
4	4.54	3.98	4.18	5.87
5	4.19	3.71	3.88	5.34
6	4.02	3.54	3.72	5.16
7	3.99	3.53	3.70	5.09
8	4.27	3.78	3.95	5.44
9	4.94	4.36	4.55	6.34
10	4.10	3.62	3.79	5.24
11	4.57	4.02	4.21	5.88
12	3.97	3.45	3.60	5.22
Average	***4.28***	***3.77***	***3.95***	***5.51***

Repeatability 2 IOPS –Average Response Time (ms) Distribution Graph



Repeatability 1 (LRT)
Measured Intensity Multiplier and Coefficient of Variation

Clause 3.4.3

IM – Intensity Multiplier: *The ratio of I/Os for each I/O stream relative to the total I/Os for all I/O streams (ASU1-1 – ASU3-1) as required by the benchmark specification.*

Clauses 5.1.10 and 5.3.13.2

MIM – Measured Intensity Multiplier: *The Measured Intensity Multiplier represents the ratio of measured I/Os for each I/O stream relative to the total I/Os measured for all I/O streams (ASU1-1 – ASU3-1). This value may differ from the corresponding Expected Intensity Multiplier by no more than 5%.*

Clause 5.3.13.3

COV – Coefficient of Variation: *This measure of variation for the Measured Intensity Multiplier cannot exceed 0.2.*

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2811	0.0700	0.2101	0.0180	0.0697	0.0351	0.2811
COV	0.005	0.002	0.004	0.002	0.011	0.003	0.007	0.002

Repeatability 1 (IOPS)
Measured Intensity Multiplier and Coefficient of Variation

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2810	0.0700	0.2100	0.0180	0.0700	0.0350	0.2811
COV	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.001

Repeatability 2 (LRT)
Measured Intensity Multiplier and Coefficient of Variation

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2812	0.0700	0.2098	0.0180	0.0700	0.0350	0.2810
COV	0.008	0.002	0.007	0.003	0.006	0.004	0.004	0.003

Repeatability 2 (IOPS)
Measured Intensity Multiplier and Coefficient of Variation

	ASU1-1	ASU1-2	ASU1-3	ASU1-4	ASU2-1	ASU2-2	ASU2-3	ASU3-1
IM	***0.0350***	***0.2810***	***0.0700***	***0.2100***	***0.0180***	***0.0700***	***0.0350***	***0.2810***
MIM	0.0350	0.2809	0.0700	0.2100	0.0180	0.0700	0.0350	0.2811
COV	0.002	0.001	0.001	0.001	0.003	0.001	0.002	0.001

Data Persistence Test

Clause 6

The Data Persistence Test demonstrates the Tested Storage Configuration (TSC):

- *Is capable of maintain data integrity across a power cycle.*
- *Ensures the transfer of data between Logical Volumes and host systems occurs without corruption or loss.*

The SPC-1 Workload Generator will write 16 block I/O requests at random over the total Addressable Storage Capacity of the TSC for ten (10) minutes at a minimum of 25% of the load used to generate the SPC-1 IOPS™ primary metric. The bit pattern selected to be written to each block as well as the address of the block will be retained in a log file.

The Tested Storage Configuration (TSC) will be shutdown and restarted using a power off/power on cycle at the end of the above sequence of write operations. In addition, any caches employing battery backup must be flushed/emptied.

The SPC-1 Workload Generator will then use the above log file to verify each block written contains the correct bit pattern.

Clause 9.4.3.8

The following content shall appear in this section of the FDR:

1. *A listing or screen image of all input parameters supplied to the Workload Generator.*
2. *For the successful Data Persistence Test Run, a table illustrating key results. The content, appearance, and format of this table are specified in Table 9-12. Information displayed in this table shall be obtained from the Test Run Results File referenced below in #3.*
3. *For the successful Data Persistence Test Run, the human readable Test Run Results file produced by the Workload Generator.*

SPC-1 Workload Generator Input Parameters

The SPC-1 Workload Generator input parameters for the Sustainability, IOPS, Response Time Ramp, Repeatability, and Persistence Test Runs are documented in "Appendix E: SPC-1 Workload Generator Input Parameters" on Page 66.

Data Persistence Test Results File

A link to each test result file generated from each Data Persistence Test is listed below.

Persistence 1 Test Results File

Persistence 2 Test Results File

Data Persistence Test Results

Data Persistence Test Results	
Data Persistence Test Run Number: 1	
Total Number of Logical Blocks Written	288,780,480
Total Number of Logical Blocks Verified	141,282,432
Total Number of Logical Blocks that Failed Verification	0
Time Duration for Writing Test Logical Blocks	10 minutes
Size in Bytes of each Logical Block	512
Number of Failed I/O Requests in the process of the Test	0

In some cases the same address was the target of multiple writes, which resulted in more Logical Blocks Written than Logical Blocks Verified. In the case of multiple writes to the same address, the pattern written and verified must be associated with the last write to that address.

PRICED STORAGE CONFIGURATION AVAILABILITY DATE

Clause 9.2.4.9

The committed delivery data for general availability (Availability Date) of all products that comprise the Priced Storage Configuration must be reported. When the Priced Storage Configuration includes products or components with different availability dates, the reported Availability Date for the Priced Storage Configuration must be the date at which all components are committed to be available.

The IBM Storwize® V7000 as documented in this Full Disclosure Report is currently available for customer purchase and shipment.

PRICING INFORMATION

Clause 9.4.3.3.6

The Executive Summary shall contain a pricing spreadsheet as documented in Clause 8.3.1.

Pricing information may be found in the Priced Storage Configuration Pricing section on page 15.

TESTED STORAGE CONFIGURATION (TSC) AND PRICED STORAGE CONFIGURATION DIFFERENCES

Clause 9.4.3.3.7

The Executive Summary shall contain a pricing a list of all differences between the Tested Storage Configuration (TSC) and the Priced Storage Configuration.

A list of all differences between the Tested Storage Configuration (TSC) and Priced Storage Configuration may be found in the Executive Summary portion of this document on page 15.

ANOMALIES OR IRREGULARITIES

Clause 9.4.3.10

The FDR shall include a clear and complete description of any anomalies or irregularities encountered in the course of executing the SPC-1 benchmark that may in any way call into question the accuracy, verifiability, or authenticity of information published in this FDR.

There were no anomalies or irregularities encountered during the SPC-1 Remote Audit of the IBM Storwize® V7000 *(SSDs)*.

APPENDIX A: SPC-1 GLOSSARY

"Decimal" *(powers of ten)* Measurement Units

In the storage industry, the terms "kilo", "mega", "giga", "tera", "peta", and "exa" are commonly used prefixes for computing performance and capacity. For the purposes of the SPC workload definitions, all of the following terms are defined in "powers of ten" measurement units.

A kilobyte (KB) is equal to 1,000 (10^3) bytes.

A megabyte (MB) is equal to 1,000,000 (10^6) bytes.

A gigabyte (GB) is equal to 1,000,000,000 (10^9) bytes.

A terabyte (TB) is equal to 1,000,000,000,000 (10^{12}) bytes.

A petabyte (PB) is equal to 1,000,000,000,000,000 (10^{15}) bytes

An exabyte (EB) is equal to 1,000,000,000,000,000,000 (10^{18}) bytes

"Binary" *(powers of two)* Measurement Units

The sizes reported by many operating system components use "powers of two" measurement units rather than "power of ten" units. The following standardized definitions and terms are also valid and may be used in this document.

A kibibyte (KiB) is equal to 1,024 (2^{10}) bytes.

A mebibyte (MiB) is equal to 1,048,576 (2^{20}) bytes.

A gigibyte (GiB) is equal to 1,073,741,824 (2^{30}) bytes.

A tebibyte (TiB) is equal to 1,099,511,627,776 (2^{40}) bytes.

A pebibyte (PiB) is equal to 1,125,899,906,842,624 (2^{50}) bytes.

An exbibyte (EiB) is equal to 1,152,921,504,606,846,967 (2^{60}) bytes.

SPC-1 Data Repository Definitions

Total ASU Capacity: The total storage capacity read and written in the course of executing the SPC-1 benchmark.

Application Storage Unit (ASU): The logical interface between the storage and SPC-1 Workload Generator. The three ASUs (Data, User, and Log) are typically implemented on one or more Logical Volume.

Logical Volume: The division of Addressable Storage Capacity into individually addressable logical units of storage used in the SPC-1 benchmark. Each Logical Volume is implemented as a single, contiguous address space.

Addressable Storage Capacity: The total storage (sum of Logical Volumes) that can be read and written by application programs such as the SPC-1 Workload Generator.

Configured Storage Capacity: This capacity includes the Addressable Storage Capacity and any other storage (parity disks, hot spares, etc.) necessary to implement the Addressable Storage Capacity.

Physical Storage Capacity: The formatted capacity of all storage devices physically present in the Tested Storage Configuration (TSC).

Data Protection Overhead: The storage capacity required to implement the selected level of data protection.

Required Storage: The amount of Configured Storage Capacity required to implement the Addressable Storage Configuration, excluding the storage required for the three ASUs.

Global Storage Overhead: The amount of Physical Storage Capacity that is required for storage subsystem use and unavailable for use by application programs.

Total Unused Storage: The amount of storage capacity available for use by application programs but not included in the Total ASU Capacity.

SPC-1 Data Protection Levels

Protected: This level will ensure data protection in the event of a single point of failure of any configured storage device. A brief description of the data protection utilized is included in the Executive Summary.

Unprotected: No claim of data protection is asserted in the event of a single point of failure.

SPC-1 Test Execution Definitions

Average Response Time: The sum of the Response Times for all Measured I/O Requests divided by the total number of Measured I/O Requests.

Completed I/O Request: An I/O Request with a Start Time and a Completion Time (see "I/O Completion Types" below).

Completion Time: The time recorded by the Workload Generator when an I/O Request is satisfied by the TSC as signaled by System Software.

Data Rate: The data transferred in all Measured I/O Requests in an SPC-1 Test Run divided by the length of the Test Run in seconds.

Expected I/O Count: For any given I/O Stream and Test Phase, the product of 50 times the BSU level, the duration of the Test Phase in seconds, and the Intensity Multiplier for that I/O Stream.

Failed I/O Request: Any I/O Request issued by the Workload Generator that could not be completed or was signaled as failed by System Software. A Failed I/O Request has no Completion Time (see "I/O Completion Types" below).

I/O Request Throughput: The total number of Measured I/O requests in an SPC-1 Test Run divided by the duration of the Measurement Interval in seconds.

In-Flight I/O Request: An I/O Request issued by the I/O Command Generator to the TSC that has a recorded Start Time, but does not complete within the Measurement Interval (see "I/O Completion Types" below).

Measured I/O Request: A Completed I/O Request with a Completion Time occurring within the Measurement Interval (see "I/O Completion Types" below).

Measured Intensity Multiplier: The percentage of all Measured I/O Requests that were issued by a given I/O Stream.

Measurement Interval: The finite and contiguous time period, after the TSC has reached Steady State, when data is collected by a Test Sponsor to generate an SPC-1 test result or support an SPC-1 test result.

Ramp-Up: The time required for the Benchmark Configuration (BC) to produce Steady State throughput after the Workload Generator begins submitting I/O Requests to the TSC for execution.

Ramp-Down: The time required for the BC to complete all I/O Requests issued by the Workload Generator. The Ramp-Down period begins when the Workload Generator ceases to issue new I/O Requests to the TSC.

Response Time: The Response Time of a Measured I/O Request is its Completion Time minus its Start Time.

Start Time: The time recorded by the Workload Generator when an I/O Request is submitted, by the Workload Generator, to the System Software for execution on the Tested Storage Configuration (TSC).

Start-Up: The period that begins after the Workload Generator starts to submit I/O requests to the TSC and ends at the beginning of the Measurement Interval.

Shut-Down: The period between the end of the Measurement Interval and the time when all I/O Requests issued by the Workload Generator have completed or failed.

Steady State: The consistent and sustainable throughput of the TSC. During this period the load presented to the TSC by the Workload Generator is constant.

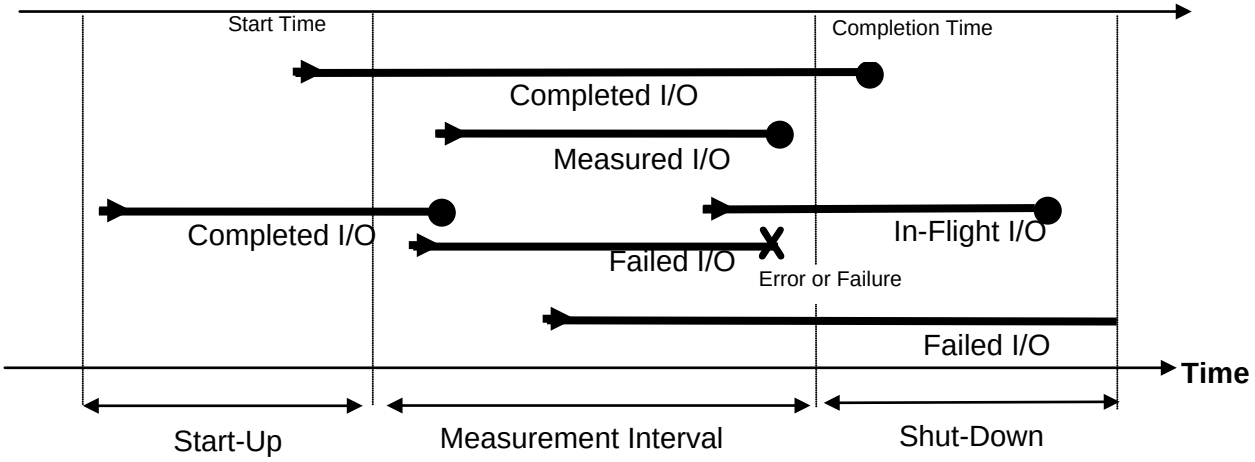
Test: A collection of Test Phases and or Test Runs sharing a common objective.

Test Run: The execution of SPC-1 for the purpose of producing or supporting an SPC-1 test result. SPC-1 Test Runs may have a finite and measured Ramp-Up period, Start-Up

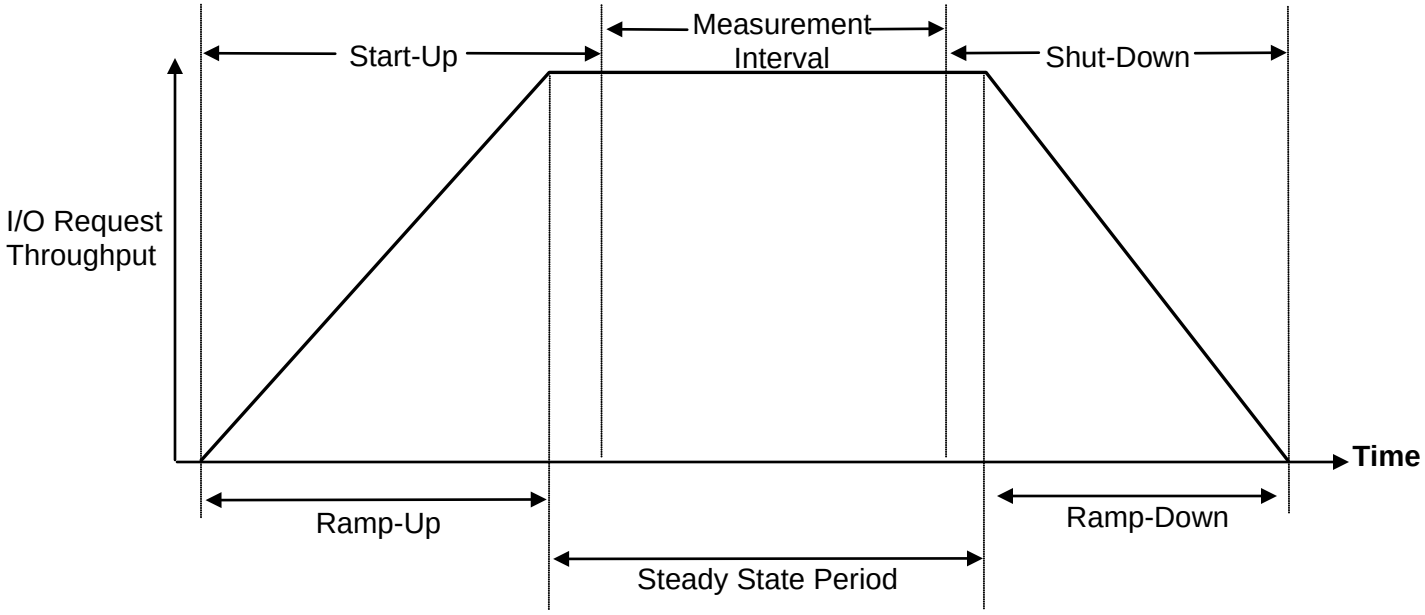
period, Shut-Down period, and Ramp-Down period as illustrated in the "SPC-1 Test Run Components" below. All SPC-1 Test Runs shall have a Steady State period and a Measurement Interval.

Test Phase: A collection of one or more SPC-1 Test Runs sharing a common objective and intended to be run in a specific sequence.

I/O Completion Types



SPC-1 Test Run Components



APPENDIX B: CUSTOMER TUNABLE PARAMETERS AND OPTIONS

The queue depth of each hdisk was changed to 256 from the default of 20 as described in *Appendix C: Tested Storage Configuration (TSC) Creation*.

APPENDIX C: TESTED STORAGE CONFIGURATION (TSC) CREATION

Each script reference, in the following TSC creation sections, is a hyperlink to the actual script. All scripts appear following the last TSC creation section, **AIX Configuration**.

Storwize V7000 Configuration

The scripts, referenced below, are executed in a **Cygwin** command window, on the AIX Host System, by invoking the name of the script from the directory where it is located.

The scripts use the **PuTTY** command ***plink***, invoked as ***plink 'name of system'*** to give a command to a specific Storwize V7000 system previously placed into **PuTTY**'s cache of known network locations. This command was used to invoke the needed Storwize V7000 setup processing.

Step 1. Define upper paths

The V7000 system is connected to the AIX host via two switches. The WWPN's associated with each active host HBA port are defined by the script **step1_mkhosts.cyg**.

Step 2. Define RAID ranks

The V7000 system has 18 solid state devices (SSDs), which were divided into pairs in order to form nine RAID-1 ranks using the script **step2_mkarrays.cyg**. All nine of the RAID-1 ranks were placed into a single storage pool.

Step 3. Create volumes for use by the Host System

From the available space in the storage pool, 8 volumes were defined for use by the Host System using the script **step3_mkvols.cyg**. Each volume is striped across the storage pool.

Step 4. Map volumes available to AIX

The volume mappings needed so that each volume is made available via either of two switches, are created by the script **step4_mapfcs_pair.cyg**.

AIX Configuration

The definition of the host configuration was done in the following sequence. All commands during the AIX portion of setup processing were issued as root in a standard command shell.

Step 1. Discover hdisks

Run the command ***cfgmgr*** to discover the available volumes. Invoke the script **queue256.sh** to change the queue depth of each volume *(hdisk as seen by AIX)* to 256.

Step 2. Define a striped logical volume group

Define a logical volume group with 18 striped logical volumes, each containing 1280 partitions of size 64 MiB. It is striped across the available 8 hdisks. This is accomplished using the script **stripethem.sh**, which was invoked as follows: ***stripethem.sh 1280 64***.

Each of the resulting 18 striped logical volumes is an SPC-1 Logical Volume from which the three SPC-1 ASUs are defined.

Referenced Scripts

step1_mkhosts.cyg

```
#!/usr/bin/bash
# run in cygwin command line

plink="plink perfv1"

$plink svctask mkhost -force -name fcs0  -hbawwpn 10000000C954CC82
$plink svctask mkhost -force -name fcs2  -hbawwpn 10000000C954C9A2
$plink svctask mkhost -force -name fcs8  -hbawwpn 10000000C95984B8
$plink svctask mkhost -force -name fcs10 -hbawwpn 10000000C960E844
$plink svctask mkhost -force -name fcs12 -hbawwpn 10000000C95A9732
$plink svctask mkhost -force -name fcs16 -hbawwpn 10000000C9548F6A
$plink svctask mkhost -force -name fcs20 -hbawwpn 10000000C954CC24
$plink svctask mkhost -force -name fcs22 -hbawwpn 10000000C954723E
```

step2_mkarrays.cyg

```
#!/usr/bin/bash
# run in cygwin command line
# Creates 9 RAID-1 arrays

plink="plink perfv1"

$plink svctask mkmdiskgrp -name v7000group -ext 256

for d in 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
do
   svctask chdrive -use candidate $d
done

for arrcount in 0 1 2 3 4 5 6 7 8
do
   let dr1="2*arrcount"
   let dr2="dr1+1"
   $plink svctask mkarray -level raid10 -drive $dr1:$dr2 -name md$arrcount
v7000group
done
```

step3_mkvols.cyg

```
#!/usr/bin/bash
# run in cygwin command line


plink="plink perfv1"


for v in 0 1 2 3 4 5 6 7
do
   let cap=184
   let lode="1+(v/4)"
   $plink svctask mkvdisk -vtype striped \
     -size $cap -unit gb -mdiskgrp v7000group -iogrp 0 \
     -name vd$v -node lode$lode
done
```

step4_mapfcs_pair.cyg

```
#!/usr/bin/bash
# run in cygwin command line
# Maps all vdisks to a pair of fcs's.
# All preferred mappings are performed first, followed by alternate mappings.

# The following is a map of where the host fcs's are in the two switches (left=lower
ports, right=upper)
hostfcs=( \
     16    8           2    22     \
     10    0           12   20    )

lastvd=`$plink svcinfo lsvdisk -nohdr -delim : | cut -f 2 -d : | cut -c 3- | awk
'($1 > b) {b=$1} END{print b}'`

for nextpos in 1 2
  do
  if [[ $nextpos -eq 1 ]]
  then
    pos=( 0 4 2 6 1 5 3 7 )
  else
    pos=( 7 3 5 1 6 2 4 0 )
  fi
  i=0
  while [[ $i -le $lastvd ]]
    do
    let k="i%8"
    j=${pos[k]}

    $plink svctask mkvdiskhostmap -force -host fcs${hostfcs[j]} vd$i

    let i="i+1"
    done
  #if windows rescan here
  done
```

queue256.sh

```
# sets hdisk queue depths to 256

hfield=$(lsdev -Cc disk | grep 'IBM 2145' | awk '{print $1}')

for h in $hfield
do
chdev -h hdisk$h -a queue_depth=256
done
```

stripethem.sh

```
# makes striped volume group from available hdisks; makes vols with a specified number
of specified meg partitions.
# important: assumes MPIO, assumes no. of hdisks divides no. of partitions.
if [[ ($# -lt 2) ]]
then
    echo "usage: stripethem partitions psize [nvols].  Partitions should be divisible
by hdisks"
    exit
fi
partspervol=$1
psize=$2

hfield=$(lsdev -Cc disk | grep 'IBM 2145' | awk '{print $1}')
if [ -e /dev/thinstripevg ]
then echo "Volume group already exists, using existing LVG"
else mkvg -fy thinstripevg -S -P 2048 -s $psize $hfield
fi

hnum=`echo $hfield | wc -w`
parts=`lsvg thinstripevg | grep "FREE PPs:" | awk '{print $6}'`
let numlv="parts / partspervol"
let usedparts="partspervol * numlv"
print "At most $numlv logical volumes can be made,"
print "using $usedparts out of $parts available partitions."
if [[ ($# -eq 3) ]]
then making=$3
else making=$numlv
fi
l=1
while [[ $l -le $making ]]
do
mklv -b n -y thin$l -x 32512 -u $hnum -S 256K thinstripevg $partspervol
l=$((l+1))
done
```

APPENDIX D: SPC-1 WORKLOAD GENERATOR STORAGE COMMANDS AND PARAMETERS

The content of SPC-1 Workload Generator command and parameter file used in this benchmark to execute the Primary Metrics *(Sustainability Test Phase, IOPS Test Phase, and Response Time Ramp Test Phase)*, Repeatability *(Repeatability Test Phase 1 and Repeatability Test Phase 2)* and Persistence Tests is listed below.

```
javaparms="-Xms1280m -Xmx1280m -Xss128k -Xgcpolicy:optavgpause"
sd=default,size=85899345920
sd=asu1_1,lun=/dev/rthin1
sd=asu1_2,lun=/dev/rthin2
sd=asu1_3,lun=/dev/rthin3
sd=asu1_4,lun=/dev/rthin4
sd=asu1_5,lun=/dev/rthin5
sd=asu1_6,lun=/dev/rthin6
sd=asu1_7,lun=/dev/rthin7
sd=asu1_8,lun=/dev/rthin8
sd=asu2_1,lun=/dev/rthin9
sd=asu2_2,lun=/dev/rthin10
sd=asu2_3,lun=/dev/rthin11
sd=asu2_4,lun=/dev/rthin12
sd=asu2_5,lun=/dev/rthin13
sd=asu2_6,lun=/dev/rthin14
sd=asu2_7,lun=/dev/rthin15
sd=asu2_8,lun=/dev/rthin16
sd=asu3_1,size=76355m,lun=/dev/rthin17
sd=asu3_2,size=76355m,lun=/dev/rthin18
```

APPENDIX E: SPC-1 WORKLOAD GENERATOR INPUT PARAMETERS

The following script was used to execute the required ASU pre-fill, Primary Metrics Test *(Sustainability Test Phase, IOPS Test Phase, and Response Time Ramp Test Phase)*, Repeatability Test *(Repeatability Test Phase 1 and Repeatability Test Phase 2)*, and Persistence Test Run 1 in an uninterrupted sequence. The script also included the appropriate commands to capture the detailed TSC profile listings required for a Remote Audit.

```
rundir=`pwd`
cd /perform/spc1runs/v7000ssd/config/fill
./runfillmar6.sh
cd $rundir
export PATH=$PATH:/usr/java6/bin
export SPC1HOME=/perform/spc1install
export CLASSPATH=$SPC1HOME
export LIBPATH=$SPC1HOME/aix
export IBM_JAVADUMP_OUTOFMEMORY=false
export IBM_HEAPDUMP_OUTOFMEMORY=false
java -Xoptionsfile=javaopts.cfg metrics -b 2410 -t 28800
java -Xoptionsfile=javaopts.cfg repeat1 -b 2410
java -Xoptionsfile=javaopts.cfg repeat2 -b 2410
java -Xoptionsfile=javaoptsp.cfg persist1 -b 2410
getaixdata.sh
getv7000data.sh
getsvcdata.sh
```

Persistence Test Run 2

The following script was used to execute Persistence Test Run 2 *(read phase)* after the required TSC power shutdown and restart.

```
export PATH=$PATH:/usr/java6/bin
export SPC1HOME=/perform/spc1install
export CLASSPATH=$SPC1HOME
export LIBPATH=$SPC1HOME/aix
export IBM_JAVADUMP_OUTOFMEMORY=false
export IBM_HEAPDUMP_OUTOFMEMORY=false
java -Xoptionsfile=javaoptsp.cfg persist2
```

Java Options

The following files were used to pass Java parameter values to Slave JVMs.

javaopts.cfg

The java parameters in the file were used for the Primary Metrics and Repeatability Tests.

```
-Xms1280m -Xmx1280m -Xss128k -Xgcpolicy:optavgpause
```

javaoptsp.cfg

The java parameters in the file were used for the Persistence Test.

```
-Xmx1280m -Xss64k -Xgcpolicy:optavgpause
```