

# NWSC-3 Draft Technical Specifications

## NWSC-3: NCAR's Next-Generation High-Performance Computing and Storage System

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## 1 NWSC-3 Procurement Introduction

On behalf of the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR), the University Corporation for Atmospheric Research (UCAR) **has plans to release** a Request for Proposal (UCAR RFP000074), for the next-generation of High-Performance Computing (HPC) system and Parallel File System (PFS) to be installed at the NCAR Wyoming Supercomputer Center (NWSC). This document provides the RFP's **draft** technical specifications.

UCAR expects that the systems, herein collectively referred to as NWSC-3, shall be accepted during the first quarter of Calendar Year (CY) 2022. The final schedule will depend upon subcontract negotiations and market availability of the HPC and PFS technologies proposed by the Offeror(s). All NWSC-3 systems are expected to be operated for five (5) years subsequent to their acceptance, with options to extend support and maintenance beyond that.

### 1.1 NWSC-3 Procurement Objectives

The primary objective of the NWSC-3 procurement is to provide computational and data storage systems that will support the simulation demands of the Earth System Science (ESS) community that currently utilizes NCAR's [Cheyenne](#) system [1]. To this end, the predominant characteristic of NWSC-3 will be its ability to run not only NCAR's existing applications and workload, but also to support the future evolution of those applications, novel, emerging application areas, and the anticipated growth of NCAR's overall computational workload. An overview of NCAR's computational workload [2] summarizes key aspects of the application and job mix, and provides a quantitative assessment of how the Cheyenne system is being used.

The NWSC-3 procurement effort is focused on NCAR's production computing workload with a strong interest in considering new technologies for NWSC-3 that can improve the performance of these applications beyond current computing architectures. UCAR acknowledges the need to move towards new HPC architectures, such as those with GPU accelerators and processors that are enabled for High Bandwidth Memory (HBM). These interests are being driven by the limitations of traditional processor design, the scientific need for finer resolutions in the simulations, modeling of previously parameterized physical processes, and the convergence of modeling, simulation, data analysis, Machine Learning (ML), and Deep Learning (DL).

This RFP is structured to give Offerors the flexibility to propose a well-balanced, forward-looking solution that meets NCAR's production computing needs, while providing UCAR the flexibility to balance cost and performance trade-offs among possible system choices and within the available funding.

Definitions of terms used throughout this document and those accompanying it are contained in Article 1 of the UCAR RFP000074 Attachment 4 Sample Subcontract Terms and Conditions.

## 2 Mandatory Elements of an Offeror Response

Offerors are expected to propose an optimal HPC and/or PFS solution compatible with the NWSC-3 RFP's specifications and timeframe.

In order to mitigate risks associated with the long RFP-to-delivery lead time and the potential use of emerging technologies, the Offeror's proposed NWSC-3 HPC system and/or PFS should be architected around the Offeror's most optimal technologies that meet the NWSC-3 specifications based upon the Offeror's product roadmaps. For responses that propose emerging technologies that are not ubiquitously available in today's HPC marketplace (e.g. HBM, HBM-enabled processors, data fabrics), UCAR requests that at least one contingent substitution for those processor, memory, or interconnect technologies be provided in the Offeror's response, along with the dates when primary versus contingent architectural choices must be made to meet anticipated delivery schedules. These architectural variants should be provided in a single proposal that covers all design options, with the characteristics of the optional variants and their advantages/disadvantages presented in side-by-side comparisons, where appropriate, in both the Technical and Business/Price volumes.

**Nota bene:** An Offeror proposing only an HPC system or PFS solution may be silent on the NWSC-3 specifications inapplicable to their solution, but their proposal must address the integration and interoperability of the computational and storage systems, as well as the Offeror's ability to work with UCAR and the other resource provider to successfully deploy, test, maintain, and support a complete NWSC-3 solution. UCAR will address the details of how UCAR and the selected Offeror(s) will work together during Subcontract negotiations.

The Offeror's proposal shall address all mandatory elements listed in this section. A proposal will be deemed non-responsive and will receive no further consideration if any one of the following mandatory requirements are not met:

- 2.1 The Offeror shall provide a detailed architectural description of the proposed NWSC-3 HPC and/or PFS production system components and their corresponding test systems. The description shall be comprised of:
  - a) a high-level architectural description and diagram that includes all major components and subsystems, including each node type, characteristics of all elements of the node, and the latencies and bandwidths to move data between the node elements;
  - b) a concise description of the major architectural hardware components in the system to include: node, cabinet, rack, multi-rack or larger scalable units, up to the total system, including the high-speed interconnect, network topology, and performance characteristics, and any unique or noteworthy features of the design;

- c) a description of the storage subsystem, its interconnection with the HPC system, and its file system components;
  - d) if proposing emerging technologies that are not presently available: primary (i.e. emerging technologies) versus contingent technologies solution differences, trade-offs, and timeframe(s) for determining such architectural choices;
  - e) a description of proposed software components along with a high-level software architecture diagram that shows all major software elements;
  - f) a description of each system's physical, electrical, cooling, and facility integration requirements;
  - g) a proposed floor plan that includes details of the physical footprint of the system and all supporting components.
- 2.2 The Offeror shall provide benchmark performance results from currently available benchmark system(s) and benchmark performance projections for the proposed HPC and/or PFS solutions.
- 2.3 For both the production and test systems, the Offeror shall provide a preliminary project plan and timeline for the delivery, installation, acceptance testing, maintenance, and support services necessary to meet the NWSC-3 HPC and/or PFS specifications and target reliability through the anticipated lifetime of the systems. This should include the roles and number of any temporary or long-term Offeror personnel supporting the plan.
- 2.4 The Offeror shall describe how the proposed HPC and/or PFS solution(s) and the timeframe of NWSC-3 deployment fits into the Offeror's longer-term product roadmap, including the technologies of the proposed systems, as well as any future upgrade path for, and rack infrastructure reuse of, the proposed system(s).

### **3 Technical Specifications**

This section, with its subsections, contains UCAR's detailed NWSC-3 system design targets and performance features. It is desirable that the Offeror's design meets or exceeds all the features and performance metrics outlined in this section. Failure to meet a given specification will not make the proposal non-responsive; however, if a specification cannot be met, it is desirable that the Offeror either provide a development and/or deployment plan and schedule that will satisfy the specification, or describe the trade-offs the Offeror's solution provides in lieu of the specification.

The Offeror shall address all specifications and describe how the proposed system meets, exceeds, or does not meet the specifications. Offerors proposing only an HPC or PFS solution should respond 'N/A' to those specifications that do not apply to their proposal.

#### **3.1 NWSC-3 Resources and Funding**

The NWSC-3 systems shall be comprised of HPC production and test systems and PFS production and test systems; see §3.11 for test system specifications.

The funding available for NWSC-3 is provided in §1.3 of the UCAR RFP000074 NWSC-3 document. UCAR anticipates a deployment of NWSC-3 resources as characterized below.

- 3.1.1 The production NWSC-3 HPC and PFS solutions are currently targeted for acceptance in the first quarter of CY 2022. The final schedule will depend upon subcontract negotiations and market availability of the HPC and PFS technologies proposed by the Offeror(s).
- 3.1.2 To facilitate acceptance testing of the NWSC-3 production HPC resource, UCAR anticipates that the NWSC-3 production PFS should complete its acceptance testing before the NWSC-3 production HPC system begins acceptance testing, particularly if the PFS and HPC resources are not supplied by the same Offeror.
- 3.1.3 The test NWSC-3 HPC and PFS solutions shall be delivered, installed, and accepted as early as feasible, given technology availability, before delivery of the production resources. See §3.11 for lead-time specifications.

## 3.2 NWSC-3 Production HPC System

The NWSC-3 production system's workload will consist of a wide spectrum of job sizes, ranging from single node jobs up to and including full-system size (see the Cheyenne Workload Study [2] for details). Thus, CISL expects that the Offeror's system design will reflect scalability trade-offs vital to NCAR's overall production workload.

- 3.2.1 The Offeror shall provide a technical description of the proposed NWSC-3 production HPC system and its integration with the PFS solution.
- 3.2.2 UCAR estimates that the NWSC-3 production HPC system should achieve a computational capacity that is approximately three times that of NCAR's current Cheyenne [1] system as measured by the NWSC-3 benchmarks. See §3.8 for information on the NWSC-3 benchmarks and the Cheyenne Sustained Equivalent Performance (CSEP) metric.
- 3.2.3 The system shall consist of (1) a **computational component** comprised primarily of CPU-only nodes, with a small number of CPU-GPU nodes, and (2) a **system services component**.
- 3.2.4 The CPU-only nodes of the system's **computational component** shall have optimum memory capacity and performance while the CPU-GPU nodes shall have a minimum memory capacity of 512 GiB (gibibytes). All memory channels shall be fully and equally populated. Memory type shall be selected to maximize performance and reliability.

- 3.2.5 The CPU-GPU nodes of the system's **computational component** shall each contain between four (4) and eight (8) GPUs, interconnected within the node, each GPU with the maximum capacity of on-board, high bandwidth memory. It is preferable, but not required that CPU architecture on the CPU-GPU partition be the same as those on the CPU-only nodes. A single CPU-socket node is acceptable, provided that the CPU have enough cores to optimally manage the GPUs. The CPU-GPU computational component shall provide, at a minimum, the required aggregate CSEP performance specified in the NWSC-3 GPU specific benchmark.
- 3.2.6 The system shall have a high-speed interconnect which provides high-bandwidth, low-latency Message Passing Interface (MPI) intercommunication and minimal inter-job interference.
- a) It is desirable that the entire HPC production system (i.e. both **computational components** and the **system services component**) share a single high-speed interconnect fabric.
  - b) The CPU-GPU nodes shall have sufficient interconnect bandwidth per node to provide scalable inter-node communications, as demonstrated in the MPAS-A GPU benchmark. UCAR estimates that a minimum of one 200 Gb/s (gigabits per second) link for each pair of GPU devices will be required.
  - c) The Offeror shall describe the high-speed interconnect and its topology, performance characteristics, including the latencies and bandwidths to move data between the node elements, routing algorithm(s), mechanisms for adapting to failing links and heavy loads, and dynamic responses to failure and repair of links, nodes, and other system components.
- 3.2.7 The **computational component** shall provide reproducible numerical results for numerically stable applications and consistent wall-clock run times for applications, regardless of the portion of the system being used, where consistency is defined as the Coefficient of Variation of an application's run time from run-to-run is less than 3% in dedicated mode and less than 5% in production mode. The Offeror shall describe strategies available to system administrators and to user applications for minimizing runtime variability.
- 3.2.8 Due to the potential heterogeneous node and/or interconnect architecture of the **computational component**, the Offeror shall describe any associated scalability limitations, impacts to the high-speed interconnect, its topology and routing, and the scalability of applications running on each set of homogeneous nodes.

- 3.2.9 The system's **system services component** shall have a sufficient quantity of nodes, in a high-availability, dual power feed configuration, to provide all requisite system management and interactive services, including operational, monitoring, administrative, resource management, job scheduling, network connectivity, I/O gateway, and login-interactive nodes. UCAR plans to provide power to the system services component via Uninterruptible Power Supply (UPS) feeds. There shall be two login-interactive nodes which have processors and GPUs identical to the CPU-GPU nodes and an additional six login-interactive nodes which have processors identical to the computational component's CPU-only nodes. All login-interactive nodes shall have a minimum of 512 GiB of memory each, with all memory channels fully and equally populated. The remaining service nodes shall be of sufficient quantity and optimally configured for the services they provide. The system services component shall also be configured for expansion, so that additional login-interactive and/or service nodes can be easily added to the NWSC-3 HPC system subsequent to the initial equipment deployment.
- 3.2.10 The system shall interconnect with and interoperate with the NWSC-3 PFS solution's low-latency, RoCE-capable<sup>1</sup> 100/200 Gb Ethernet I/O network (cf. §3.3.6) to support high-bandwidth I/O operations (cf. §3.3.3) from applications utilizing the file systems hosted by the NWSC-3 PFS. The Offeror shall provide sufficient gateways and/or network switches to meet the bandwidth and connectivity requirements of the PFS system.
- 3.2.11 The system and its interconnect shall be architected to ease future expansion of the system's computational capacity and/or for future performance enhancement (e.g., via component replacement).

### 3.3 NWSC-3 Production PFS

NCAR intends to use the NWSC-3 production PFS primarily for temporary or short-term data storage for the NWSC-3 HPC system (e.g., scratch and project file systems). The Offeror shall propose hardware and software to support a high-performance PFS that presents one or more globally consistent namespace(s) to the HPC platform.

- 3.3.1 The Offeror shall provide a technical description of the proposed NWSC-3 PFS solution and its integration with the HPC system.
- 3.3.2 The Offeror shall provide a description of their PFS solution and a matrix comparing the technical features of the proposed file system software with those of IBM Spectrum Scale™.
- 3.3.3 The PFS and HPC system shall have a minimum initial sustainable aggregate read and write bandwidth exceeding 300 GB/s (gigabytes per second) as measured from the HPC system. The Offeror's proposal shall state the target minimum sustainable aggregate bandwidth of the proposed PFS solution and describe the

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<sup>1</sup> RDMA over Converged Ethernet (RoCE)



Offeror's commitment, and any contingencies, to demonstrating that target prior to Acceptance.

- 3.3.4 The PFS solution shall have an initial usable file system capacity of 60 PB and a rack infrastructure that allows the usable capacity to be doubled by the simple addition of data storage devices.
- 3.3.5 The PFS solution shall be configured with at least 40 TB of Solid-State Drive (SSD) storage, to be used for file system metadata, and a rack infrastructure which allows the usable SSD capacity to be easily doubled via future installation of SSD storage devices.
- 3.3.6 The PFS shall be architected with a low-latency, RoCE-capable, 100/200 Gb Ethernet I/O network. The HPC system will be interconnected with the PFS via this network. The Offeror shall provide sufficient gateways and/or network switches to meet the bandwidth and connectivity requirements described here, in §3.2.10, §3.3.3, and §3.4, and allow for future expansion.
- 3.3.7 The PFS solution shall be architected around the concept of a Scalable Storage Unit (SSU), to provide for future augmentation of both its aggregate I/O bandwidth and storage capacity. Each SSU should support a capacity expansion within the SSU as well as I/O bandwidth and capacity expansions through additional SSUs.

### **3.4 Integration with Existing NWSC Data Services**

NCAR currently operates the IBM Spectrum Scale™-based NCAR GLADE file system and Campaign Store services, the HPSS-based NCAR Archive, and an Ethernet-based local area network at the NWSC. The NWSC-3 HPC and PFS solutions must integrate into the overall NWSC environment and interoperate with these existing resources. The Offeror shall work with UCAR to identify appropriate technologies for accomplishing that integration.

- 3.4.1 The NWSC-3 HPC system shall connect to and interoperate with NCAR's existing Spectrum Scale™-based GLADE and Campaign Store resources. For more information, see the NCAR GLADE Integration Guide [3].
- 3.4.2 The NWSC-3 HPC and PFS solution shall each provide appropriate connectivity to NCAR's TCP/IP network.
- 3.4.3 The NWSC-3 PFS solution shall support connectivity with NCAR client systems other than the NWSC-3 HPC system and provide an aggregate, sustainable bandwidth in excess of 200 Gb/s.

### **3.5 System Software**

The Offeror shall propose a supported system software environment designed for data-intensive and compute-intensive workloads. The objective is to provide our NWSC-3 users with a high-performance, high-availability, high-reliability, and scalable system software environment that allows efficient use of the full capability of the NWSC-3 resources.

- 3.5.1 The Offeror shall provide a system that includes a full-featured Linux Operating System (OS) environment for all nodes of the system's computational and system services components; though an LSB-compliant<sup>2</sup> OS is not mandatory, application portability for multiple Linux distributions is preferred by UCAR's user community. The Offeror shall describe any restrictions within the provided OS that could limit running applications developed on any LSB-compliant Linux distribution.
- 3.5.2 The Offeror shall describe any Application Programming Interface (API) or system call(s) that are available to measure memory consumption at runtime. The Offeror shall also describe how the compute node OS will flush all user buffers associated with a job upon normal completion, or whether an API or other procedure(s) must be invoked for that purpose.
- 3.5.3 The Offeror shall describe any system software optimizations or support for a low-jitter environment for applications and shall provide an estimate of a compute node OS's noise profile, both while idle and while running a non-trivial MPI application, including jitter-induced application runtime variability. If core specialization is used, describe the system software activity that remains on cores assigned to the application.
- 3.5.4 The Offeror shall describe the HPC system software's support of application containerization, including support for parallel jobs and Application Binary Interface (ABI) compatibility with open-source MPI implementations.
- 3.5.5 The Offeror shall describe the compute partition OS's support for a trusted environment where:
- a) user processes are isolated from each other to the maximum extent possible according to the principle of least privilege and the following attributes;
  - b) user processes must run with the user's credentials and be subject to the POSIX file permission model;
  - c) user processes may be run with remapped credentials via the Linux user-namespace feature;
  - d) user processes must not be run with elevated permissions or more access than necessary for the accelerators, high-speed interconnect, or other hardware to function; and
  - e) where an unprivileged user can cause system damage or denial-of-service such as a kernel or system service crash, shall be considered a system bug to be corrected by the Offeror once reported by NCAR.

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<sup>2</sup> Linux Standards Base (LSB)

- 3.5.6 The Offeror shall provide, and briefly describe, a process for reporting and correcting vulnerabilities reported by NCAR and/or disclosed in the National Institute of Standards and Technology (NIST) [National Vulnerability Database \(NVD\)](#) [4] which impact the OS or other Offeror-provided software.
- 3.5.7 The Offeror shall describe its software development, release, and upgrade plan, as well as regression testing and validation processes, for all system software, including security and vulnerability updates.

### **3.6 Job Scheduler and Resource Manager**

The Offeror shall propose a job scheduler and resource management subsystem, with any requisite licensing, that is capable of simultaneously scheduling both batch and interactive workload within and across all portions of the NWSC-3 system.

- 3.6.1 The Offeror shall describe the proposed job scheduler and resource manager and its support for: hierarchical fair-share; backfill; targeting of specified resources; advance, persistent, and maintenance/system reservations; inter-job dependency; job preemption; monitoring of running and pending jobs; and job reporting and accounting.
- 3.6.2 The scheduler/resource manager shall be capable of launching applications requesting resources from a single core up to full-system scale. The Offeror shall describe:
- a) support for balancing large and/or full-system jobs with large volumes of smaller jobs and for facilitating prompt dispatch of large jobs without administrator intervention or unnecessary loss of efficiency,
  - b) the architecture-aware job-placement algorithm and its effect on job runtime, the variability of job runtime and performance, and job latency,
  - c) expected application launch times, the factors that affect launch time (e.g.: executable size, number of jobs currently running or queued) and how various factors increase or decrease the launch time, and
  - d) how resource allocation for a job, job-matrix, or a set of interdependent jobs is maintained after an unexpected hardware or software interrupt, and is able to relaunch the job.
- 3.6.3 The Offeror shall describe the scheduler/resource manager's support for combining on-premises resources with public Cloud resources to process workloads suitable for Cloud-bursting to the public Cloud, such as [Amazon EC2](#), [Google Cloud Platform](#), and [Microsoft Azure](#).
- 3.6.4 The Offeror shall describe the performance characteristics of the job-scheduler, addressing the following criteria at a minimum: the maximum job-throughput rate, the maximum number of queued jobs, and the supported rate of simultaneous job status queries at maximum job-throughput while supporting a workload utilizing all of the features described in §3.6.1.
- 3.6.5 The Offeror shall commit to conducting the NWSC-3 HPC system's Acceptance Testing with the selected scheduler/resource manager in a configuration

approximating CISL's current production environment and conducting the scheduler evaluation and testing described in UCAR RFP000074 Attachment 4F Sample Subcontract Schedule F Acceptance Criteria and Testing.

### **3.7 Programming Environment and Software Tools**

For the following software categories, the Offeror should describe the proposed set of the Offeror's optimized, integrated software tools included with the systems.

- 3.7.1 To support climate and weather models that make up the large majority of NCAR's production workload, the Offeror's proposed system shall support an efficient hybrid MPI/OpenMP programming model.
- 3.7.2 The Offeror shall propose one Offeror-supported MPI implementation and recommend one other MPI implementation, both conforming with the MPI version 3.1 standard. The Offeror shall describe the proposed MPI implementation(s), including: MPI standard version, standard compliance and limitations; optimizations for collective operations; support for features such as hardware-accelerated collectives; and the ability for applications to access the physical-to-logical mapping of the job's node allocation.
- 3.7.3 The system shall include an implementation of OpenMP 4.5 and anticipate support for the OpenMP 5.0 standard. The OpenMP support should provide for future execution offload to GPUs. The Offeror shall describe the OpenMP support to be provided with the system.
- 3.7.4 The Offeror shall provide and describe Offeror-supported, high-performance, optimizing Fortran, C and C++ compiler suites for both the CPU-only and CPU-GPU portions of the HPC system; preferably PGI, plus at least one additional compiler (e.g., Intel, AOCC, ARM). The compilers shall support OpenACC, CUDA, OpenCL, OpenMP execution offload to GPU. Licensed compilers shall support a minimum of fifty (50) concurrent users.
- 3.7.5 The Offeror shall describe the system's support for building containerized applications and running such applications, whether built locally or elsewhere.
- 3.7.6 The Offeror shall describe elements of the provided software stack which support data analytics and machine learning software.
- 3.7.7 The Offeror shall describe support for performance measurement capabilities, including mechanism for accessing CPU and other system performance counters.
- 3.7.8 The Offeror shall describe any proposed software components that provide control of task CPU and memory placement within a node or among nodes for efficient and consistent performance of applications, the controls provided, and any limitations that may exist.

### **3.8 Application Performance Specifications and Benchmarks**

Assuring that NCAR's applications perform well on the NWSC-3 platform is critical to the success of the system. Because NCAR's full applications are large, CISL has developed a reduced benchmark suite to assess performance and scalability as part of the NWSC-3 proposal evaluation and during system acceptance.

- 3.8.1 The NWSC-3 benchmarks shall be run in accordance with the guidance provided in UCAR RFP000074 Attachment 2, NWSC-3 Benchmark Rules and the instructions provided on the [NCAR Benchmarks](#) website [5].
- 3.8.2 The Offeror shall provide NWSC-3 benchmark (1) actual performance results from the Offeror's existing benchmark system(s) and (2) predicted performance results for the proposed system(s). The Offeror shall report the results of the benchmarks in the UCAR RFP000074 NWSC-3 Benchmark Results Spreadsheet, available from the [NWSC-3 RFP](#) website [6].
- 3.8.3 UCAR expects the NWSC-3 production HPC system to deliver a computational capacity of approximately three (3) CSEPs (Cheyenne Sustained Equivalent Performance units) as calculated by the UCAR RFP000074 NWSC-3 Benchmark Results Spreadsheet. The Offeror's proposal shall state a target minimum CSEP commitment for the proposed NWSC-3 production HPC system and the system shall meet or exceed the Offeror's target minimum CSEPs during Acceptance testing. The Offeror's proposal shall describe the Offeror's commitment to, and any contingencies for, meeting the target minimum CSEPs.
- 3.8.4 Following award, and prior to delivery of the production NWSC-3 system, the Offeror shall validate that the production HPC system generates correct numerical results for all the applications in the benchmark suite. The validation runs will be performed jointly by the Offeror and CISL staff. These runs will be conducted during the Factory Trial (cf. §3.2 of UCAR RFP000074 Attachment 4F Acceptance Criteria and Testing) or may be made on a system with the same processor and interconnect technology that will comprise the production HPC system.
- 3.8.5 All performance tests shall, throughout the lifetime of the system, continue to meet or exceed the performance measured during Acceptance testing and their numerical results reproducibility criteria.

### **3.9 Reliability, Availability, and Serviceability**

For each attribute specified below, the Offeror shall describe how the system will meet or exceed the specification, and the Offeror's commitment to doing so. The definition of terms used in this section can be found in Article 1 "Definitions" of UCAR RFP000074 Attachment 4, NWSC-3 Sample Subcontract Terms and Conditions. Since system reliability, availability, and serviceability (RAS) are very important to UCAR's user community, the system should be architected with enhanced availability and reliability features to enhance the user experience and meet the specified availability targets (§3.9.1 through §3.9.3).

- 3.9.1 The lifetime System Availability of the **computational component** of the NWSC-3 production HPC system shall exceed 98.5%.
- 3.9.2 The lifetime System Availability of the **system services component** (cf. §3.2.9) of the NWSC-3 production HPC system shall exceed 99%.
- 3.9.3 The lifetime File System Availability of the NWSC-3 production PFS shall exceed 99%.
- 3.9.4 The Offeror shall describe how the system software tracks early signs of system faults and reports information about the hardware and software from all components in the system.
- 3.9.5 The Offeror's proposal shall discuss the RAS mechanisms and capabilities of the proposed HPC and PFS solutions including, but not limited to:
  - a) resiliency features to achieve the availability targets;
  - b) single points of failure, hardware or software, or any other condition that can potentially affect running applications, cause a job interrupt, and affect system availability;
  - c) how a file system remains available when a PFS component (server, controller, drive) fails;
  - d) a system-level mechanism to collect failure data for each kind of component.
- 3.9.6 Failure of the HPC or PFS management systems or RAS mechanisms shall not cause a full system or file system interrupt. This does not apply to a RAS system feature that automatically shuts down the system for safety reasons.

### **3.10 System Management and Operations**

The Offeror shall provide a centralized ability to manage and operate the HPC and PFS solutions independently as specified in the following subsections.

- 3.10.1 The Offeror shall describe the proposed HPC system and/or PFS management, monitoring and operation infrastructure, including its networking, number of management and boot nodes, boot file systems, and other requisite infrastructure used for system management and operation.
- 3.10.2 The HPC system and/or PFS management and monitoring capabilities shall be centralized, integrated, and scalable and provide: human interfaces and APIs for system configuration and an ability to be automated; software management; change management; and local site integration and customizations. The description shall include the effects and overhead of software management and monitoring components on CPU, network, and/or memory of system nodes.
- 3.10.3 The Offeror shall describe how the HPC system and/or PFS can be monitored, operated, power managed, and administered from a remote location via lights-out management.

- 3.10.4 The Offeror shall describe the environmental monitoring capabilities provided with the system (e.g. thermal, power consumption, cooling), the granularity of such monitors (e.g. hardware component, sampling rate), and any support for real-time observation of measurements and automated alerts.
- 3.10.5 The Offeror shall, for the HPC system and/or PFS, describe and provide a means for tracking and analyzing of all software and firmware updates, software and hardware changes and failures, and hardware replacements over the lifetime of the system. Centralized management support shall include:
- a) updates that do not require full-system outages shall allow previous version and next version to be simultaneously running on independent nodes, or partitions, of the production system;
  - b) support for multiple simultaneous or alternative system software configurations; and
  - c) notwithstanding upgrades required for reasons such as security, it is desirable that all system software be upgradeable without the need for complete reinstall or major operational interruptions.
- 3.10.6 The Offeror shall provide an ability for UCAR to promptly obtain updates for all software and firmware supplied with the NWSC-3 HPC system and/or PFS. Processes should allow expeditious updating of kernel and non-kernel packages to address issues that impact user application and system performance, including security vulnerabilities, in the suite of software, preferably via an integrated cluster management interface. The Offeror shall provide guidance on Offeror tested/recommended software stack versioning and best practices. This shall include new releases of software/firmware and software/firmware features, bug fixes, and security patches as required.
- 3.10.7 The Offeror's proposed HPC system and/or PFS management capabilities shall provide:
- a) a single, scalable log analysis capability for all logs originating from any component of the proposed system;
  - b) log history that is persistent, or at least enough for at least one week at syslog level "debug" or equivalent on all components;
  - c) user activity tracking, such as audit logging and process accounting; and
  - d) the ability to store a second copy of the logs for the PFS to facilitate independent analysis.
- 3.10.8 CISL system administrators shall have unrestricted privileged access to all hardware and software components delivered with the system.

- 3.10.9 The Offeror shall describe the full HPC system initialization sequence and timings, including the time to complete the system initialization. HPC system initialization is defined to be the time to power up and initialize 98.5% of the installed **computational component** of the system and 100% of any **system services component** to the point where a job can be successfully launched. It is desirable that HPC system initialization can be accomplished within forty-five (45) minutes.
- 3.10.10 The Offeror shall describe the full PFS system initialization sequence and timing, including the time to complete the PFS initialization. PFS initialization is defined to be the time to power up and initialize all file system servers, controllers, and subsystems to the point where all hosted file systems can be accessed from applications running on external clients.
- 3.10.11 The Offeror shall provide CISL with a complete listing of all components and systems along with associated documentation and/or manuals, and a plan for support of offline backups and bare metal recovery of all components and systems. This should include any procedures required to configure components for remote administration, including, but not limited to, UEFI/firmware parameters and BMC/IMM parameters.<sup>3</sup>

### 3.11 Test Systems

The Offeror shall propose test HPC and/or PFS systems. The test systems will be used by CISL for testing upgrades to the production NWSC-3 systems, therefore they shall contain all the same hardware, software, and functionality as the production systems, but scaled down to an appropriate testable configuration.

- 3.11.1 A test system shall be comprised of:
- a) **HPC**: The smallest unit of computational nodes conforming with either the Offeror's scalable unit, or a suitable architectural unit, configured similarly to the NWSC-3 production HPC system, including all system service nodes and two login-interactive nodes;
  - b) **PFS**: The smallest unit conforming with either the Offeror's scalable unit, or a suitable architectural unit, sufficient to constitute a dedicated test PFS, configured similarly to the NWSC-3 production PFS, with SSDs for metadata;

and all requisite administrative resources to be independently administrable and operable from the corresponding production system. Components that are redundant in the production systems shall also be present in the test systems as redundant components.

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<sup>3</sup> UEFI, BMC, and IMM are Unified Extensible Firmware Interface, Baseboard Management Controller, and Integrated Management Module, respectively.



- 3.11.2 The test system shall be capable of operating entirely independent of the NWSC-3 production system such that no Offeror-provided components are shared between the test and the production systems.
- 3.11.3 The test system shall be sized such that any procedures for the production system shall be testable on the test system, including firmware and software upgrades, patches, administration, operation, and monitoring. Exceptions should be noted in the Offeror's proposal.
- 3.11.4 While it is desirable that a test system, or its augmentation, shall be delivered to and installed at the NWSC ninety (90) or more days prior to its corresponding production equipment delivery, UCAR requires a minimum of sixty (60) days.

### **3.12 Facilities and Site Integration**

NWSC facility specifications are provided below in Table 1 and target NWSC-3 HPC and PFS locations within the NWSC facility are shown below in Figure 1. These are intended to assist Offerors in understanding the integration requirements for NWSC-3 and related systems, and are subject to change prior to the NWSC-3 deployment. The following subsections describe facility-related attributes for the NWSC-3 systems.

- 3.12.1 The production NWSC-3 HPC system will be housed in the NWSC Module A, which is being built out to support the system. The remainder of the NWSC-3 systems (test HPC, production PFS, and test PFS) will be housed in the NWSC Module B.
- 3.12.2 The NWSC-3 HPC systems shall use 3-phase 400V to 480V AC power. Both four- and five-wire cabling can be accommodated. If line-to-neutral power supplies are used, phase balancing is necessary and shall be verified at the NWSC. Other power sources (208V, 110V) are available to support a system's infrastructure such as storage, switches, and consoles. Power cable cord lengths shall comply with all applicable manufacturing standards and NFPA70 National Electrical Code (NEC) 645.5(B). The maximum power-supply cord length is 15 feet.
- 3.12.3 All equipment and power control hardware shall be Nationally Recognized Testing Laboratories (NRTL) certified. All equipment shall bear appropriate NRTL labels. All equipment shall comply with the Institute of Electrical and Electronics Engineers (IEEE), National Electrical Code (NEC), and National Fire Protection Association (NFPA) environmental standards and codes, particularly for Performance Level 2 systems as defined in IEEE 1156.2-1996. All proposed equipment shall comply with the Class A1 & A2 recommended operating environment ranges as specified in the ASHRAE<sup>4</sup> TC 9.9 2011 Environmental Guidelines for Data Processing Environments.

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<sup>4</sup> American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

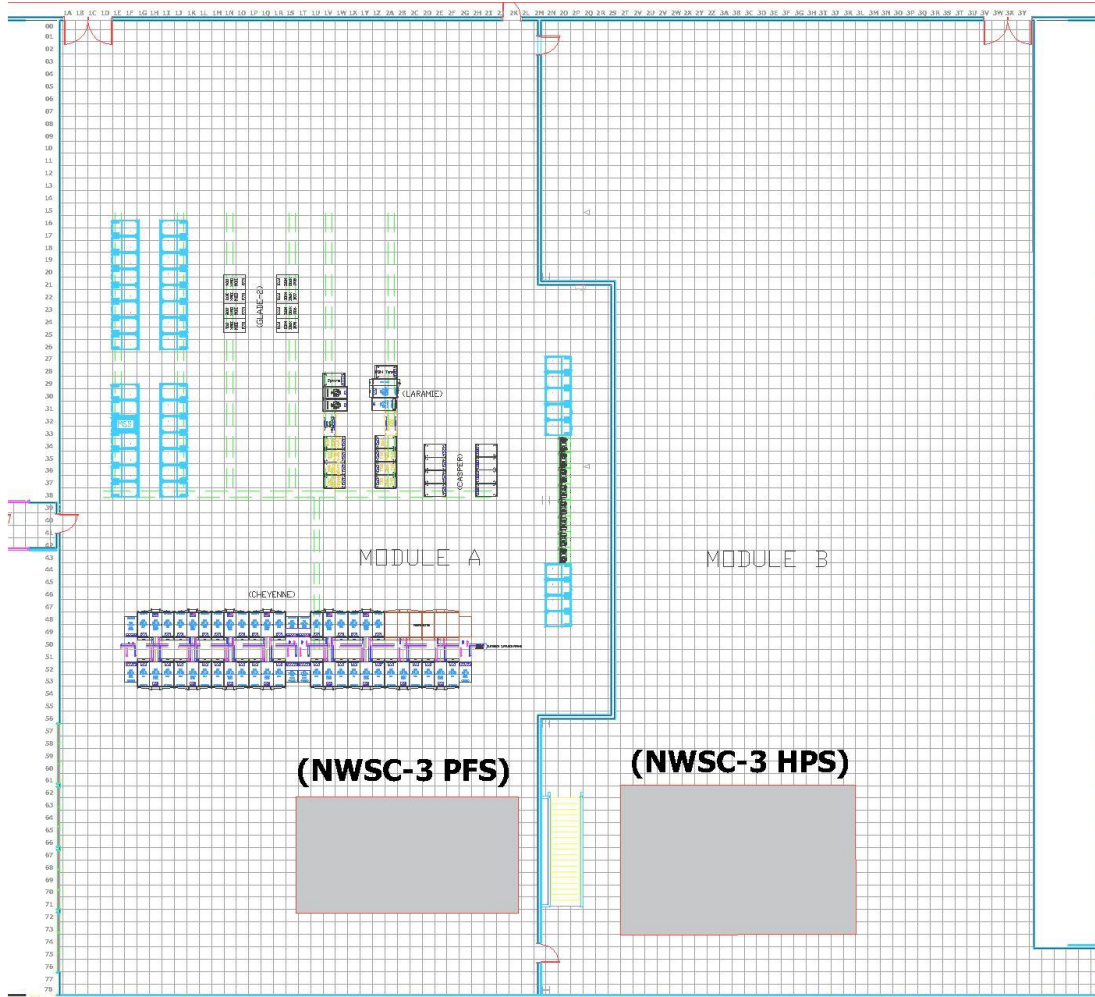
- 3.12.4 It is desirable that the NWSC-3 production HPC and PFS network devices can be powered from separate power sources regardless of their location inside the NWSC-3 systems.
- 3.12.5 It is desirable that any critical mechanical equipment (e.g. cooling units, pumps) can be powered by a power source separate from the computational resources so they can be put on UPS.
- 3.12.6 All system components (e.g. rack, network switch, interconnect switch, node, disk enclosure, cable) shall be physically labeled with a unique identifier, matching its designation in software, and other identifying data (e.g. component serial number). These labels shall be visible from any service access points, and of high quality to not degrade and be readable throughout the lifetime of the system. Each rack shall additionally have a component layout chart providing similar information which, ideally, can be recreated whenever components are replaced.
- 3.12.7 All NWSC-3 system power cabling and water connections shall be below the access floor. All other cabling (e.g. system interconnect, administrative networking) shall be above floor. The systems shall be provided with cable containment integrated with and spanning between the system racks to accommodate the system interconnect and networking cables. All cables shall be plenum rated, neatly bundled and secured, and labeled with source/destination and a unique identifier at both ends.
- 3.12.8 The Offeror's proposal shall provide a Machine Unit Specification (MUS) chart for the proposed production and test systems and describe the features of the system related to facilities and site integration including:
- a) Detailed descriptions of power and cooling distributions throughout the system including power consumption and cooling requirements for all subsystems at idle, observed operational maximum, and design limit states.
  - b) Detailed descriptions, quantities and types of all electrical and mechanical connections made to facility infrastructure.
- 3.12.9 The Offeror's proposal shall provide a floor plan diagram and AutoCAD file (utilizing the NWSC AutoCAD file provided on the [NWSC-3 RFP](#) website [6]) showing proposed production and test HPC system and/or PFS placement.
- 3.12.10 The Offeror's proposal shall describe the remote environmental monitoring capabilities of the system and any accommodation for integration with the NWSC's facility monitoring.
- 3.12.11 The Offeror's proposal shall provide a description of the Offeror's facility and installation planning services. The description shall include the facility preparation and planning processes to be conducted with UCAR and logistics information, including shipping, receiving, and staging of NWSC-3 equipment and any on-site assembly thereof.

- 3.12.12 The Offeror shall provide transportation, delivery, and installation of all NWSC-3 equipment, replacement parts and spare parts. The Offeror shall provide unpacking, uncrating, assembly, and interconnection of the NWSC-3 system components at the NWSC facility in Cheyenne, WY. The Offeror shall remove all packing materials and trash associated with delivery and installation.

**Table 1.** NWSC Facility Specifications

<b>Specification</b>	<b>Description</b>
Location	NCAR Wyoming Supercomputer Center, Cheyenne, Wyoming
Altitude	6,260 feet
Seismic	N/A
Water Cooling	The system shall operate within ASHRAE TC 9.9 2011 Class A1 and A2 temperature ranges. The NWSC provides 65F chilled water and can accommodate return temperatures up to 80F without coordination with or modifications to the NWSC facility. The NWSC chilled water system can accommodate a large range of flow rates. Deionized water is available.
Air Cooling	The system shall operate within ASHRAE TC 9.9 2011 Class A1 and A2 temperature ranges.
Maximum Power	3 MW
Maximum Power Rate of Change	No restrictions
Floor	10' raised floor
Ceiling	12' ceiling; maximum cabinet height is 9'9"
Maximum Footprint	12,000 square feet (inclusive of compute, storage, and service aisles)
Shipment Dimensions and Weight	For delivery, system components shall weigh less than 7,000 pounds. All doors and pathways are 6'0" in width and 9'9" in height, or larger.
Floor Loading	Data Room floor of the NWSC facility can handle a point load of 2500 pounds or a uniform load of 625 pounds per SF. The rolling loads are less, with a point load capacity of 2000 pounds."
External network interfaces supported by	1GbE, 10GbE, 40GbE, 100GbE, 200GbE

the site for connectivity requirements (specified below)	
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**Figure 1. NWSC Modules A and B Floor Plan**

This figure shows the existing equipment and suggested areas for the location of the NWSC-3 PFS and HPS system (referred to here as HPS) within the floor plan of the NWSC Modules A and B.

### 3.13 Maintenance, Support, and Technical Services

The Offeror shall propose maintenance, support, and technical services with the following minimum features:

- 3.13.1 The Offeror shall propose technical services, warranty, maintenance, and support for the NWSC-3 system hardware and software for a period of five (5) years subsequent to the date of Acceptance of the NWSC-3 production HPC system and/or PFS by UCAR. Maintenance and support pricing shall be for each year after the warranty expires. The warranty period begins at the date of Acceptance of the system.
- 3.13.2 The Offeror shall describe proposed maintenance and support services which, at a minimum: (1) provide replacement hardware for all failed components and return shipping of failed components to the Offeror, (2) train and certify CISL technicians (cf. §5.2) to perform hardware failure isolation, diagnosis, ticketing, reporting, and repair/replacement activities for all Customer-Replaceable Units (CRUs) components, (3) provide Offeror technicians to perform repair/replacement activities for all FRU components, and (4) supply hardware maintenance procedure documentation, training, manuals, and instructional videos. UCAR's target for on-site Offeror responsiveness is 9x5-NBD (Next Business Day), though more immediate response should be available for critical downtime situations. UCAR strongly prefers that maintenance and support personnel and services be directly supplied by the Offeror rather than Offeror-contracted.
- 3.13.3 Any component of the NWSC-3 production HPC and PFS systems that fails shall be expeditiously repaired. It is desirable that CRU be repaired/replaced by Offeror-trained CISL technicians by utilizing parts from an on-site spare parts cache and that Field-Replaceable Units (FRUs) be repaired/replaced by Offeror technicians. No component may fail and remain out of service longer than seven (7) calendar days unless mutually agreed to by UCAR and the Offeror.
- 3.13.4 The Offeror shall provide and maintain an on-site spare parts cache at the NWSC facility and any storage cabinetry required to contain the cache. All spare parts shall be Original Equipment Manufacturer (OEM) replacement parts with firmware levels that match those of the corresponding production NWSC-3 system.
- a. The initial provisioning of the cache shall be based on the Offeror's Mean Time Between Fails (MTBF) estimates for each CRU and FRU, and on the number of CRUs and FRUs delivered in the system.
  - b. The on-site parts cache shall be provisioned sufficiently to support all normal repair actions for four weeks without the need for inventory refresh and replenishment of failed parts by the Offeror shall occur within two weeks, unless otherwise agreed between UCAR and the Offeror.
  - c. The on-site parts cache inventory shall be periodically reviewed by UCAR and the Offeror and, should the on-site parts cache prove to be insufficiently stocked either by CRU/FRU or in quantity, be augmented and/or resized at the Offeror's expense.
  - d. It is desirable that an inventory management system is available for the on-site parts cache that is capable of tracking the on-site inventory and producing itemized inventory lists (e.g., weekly, on-demand) of available, consumed,

replaced and back-ordered parts, along with associated part identifiers (e.g., serial number, firmware revision).

- 3.13.5 The Offeror shall provide technical support services with 24x7 telephone and web-based technical support, problem reporting, ticketing, diagnosis, and resolution services. UCAR shall be able to contact and receive assistance from Offeror technical staff for software and hardware problem diagnosis and resolution. The Offeror shall provide procedures for problem escalation up to and including continuous 24x7 support for critical situations. The Offeror's problem reporting and ticketing system shall be fully functioning and provide participant roles, keyword searches, a unified view of hardware and software problem reports/resolutions, the ability to transition and associate tickets between hardware and software, and the ability to generate periodic (e.g., weekly, monthly, on-demand) detailed and summary reports of all tickets based upon user-selectable filter criteria.

## **4 Technical Options**

This section contains requested options to the NWSC-3 systems and services described in §3. The Offeror shall provide all relevant technical, business and price information, in the appropriate proposal volumes as described in the UCAR RFP000074 NWSC-3 RFP document, for each of the options listed below. Additionally, UCAR encourages Offerors to propose potential collaborative efforts which may be mutually beneficial.

Pricing information for all proposed options should be provided in the Business/Price volume of the Offeror's proposal.

### **4.1 On-site System Administrator**

If not already included by the Offeror in the support services proposed in response to §3.13, the Offeror shall describe option(s) for UCAR to obtain, on a person-year basis, Offeror personnel to provide on-site system administration, maintenance, and software support for the NWSC-3 system(s).

### **4.2 On-site Software and Firmware Upgrade Support**

If not already included by the Offeror in the support services proposed in response to §3.13, the Offeror shall describe option(s) for UCAR to obtain, on a person-month basis, Offeror personnel to provide on-site assistance for software and firmware updates to the NWSC-3 system(s). This shall include new releases of software and firmware, and software and firmware patches, as required.

### **4.3 Remote Support Services**

If not already included by the Offeror in the support services proposed in response to §3.13, the Offeror shall propose an option which would make key technical personnel with knowledge of the proposed NWSC-3 software and systems available to NCAR, on a person-month basis, for consultation by telephone and email with NCAR personnel and to support NCAR personnel with application porting, development, and optimization activities.

#### **4.4 PFS Capacity Expansion Options**

The Offeror shall include options to increase the usable production PFS file system capacity to 120 PB (petabytes) and to increase the usable metadata SSD capacity to 80 TB (terabytes) by the simple addition of storage devices.

#### **4.5 Early Access Development System**

To allow for early and/or accelerated development of applications, development of functionality required for NWSC-3 as a part of the Subcontract's statement of work, or for the correctness validation of the NWSC-3 benchmark results, the Offeror shall propose one or more options for an Early Access Development System (EADS). An EADS can be a stand-alone system delivered to NCAR, an augmentation of an NWSC-3 test system, or a system provided to UCAR via remote access and located at the Offeror's site. EADS(s) should be delivered or made available at least six (6) months prior to the delivery of any hardware or software that is planned for production.

- 4.5.1 The Offeror may propose one or more EADS. The primary purpose is to expose NCAR applications to the same architecture (processor, GPU, interconnect, memory, and other technologies) and programming, runtime, administrative, and system software environment as will be found on the NWSC-3 system.
- 4.5.2 The specific size of the EADS shall be negotiated with Offeror and will be based on the details of the specific NWSC-3 system and other proposed options.

### **5 Documentation and Training**

The Offeror shall provide documentation and training for the NWSC-3 HPC system and/or PFS to CISL operators, system administrators, and user services staff so that they may effectively operate, configure, and monitor the systems and assist users of the systems. The Offeror shall grant NCAR use and distribution rights of Offeror-provided documentation, training session materials, and recorded media to be shared with NCAR staff and authorized users and support staff for the NWSC-3 systems.

#### **5.1 Documentation**

The Offeror shall provide the following forms of documentation for the NWSC-3 systems.

- 5.1.1 Prior to the commencement of system acceptance testing, the Offeror shall provide system-level documentation for each delivered system describing the configuration, logical and physical interconnections, interconnect topology, labeling and naming schema, and hardware layout of the system as deployed, including any Offeror customizations made to the system and intellectual property created by the Offeror or its subcontractors to meet UCAR's NWSC-3 specifications.
- 5.1.2 The Offeror shall supply and support system-level documentation required for the proper operation and maintenance of the system. Documentation shall include available monitoring APIs available for use by CISL for enhanced monitoring capabilities.

- 5.1.3 The Offeror shall supply user-level documentation that can be shared with authorized users of the NWSC-3 systems for any user-accessible software tools and programming environment components. The Offeror shall describe any limitations on UCAR's redistribution of these materials.
- 5.1.4 The Offeror shall describe how system-level and user-level documentation will be distributed and updated electronically.

## 5.2 Training

The Offeror shall provide the following forms of training for the NWSC-3 HPC and PFS systems.

- 5.2.1 The Offeror shall provide the types of training listed in Table 2 at facilities specified by UCAR.

**Table 2.** List of Required Offeror-Provided Training

Class Type	Number of Classes Provided Annually	
	Initial Year	Subsequent Years (if necessary)
CRU hardware maintenance and Offeror Service Portal(s)	2	1
System Operations and Advanced Administration	1	1
HPC-only: Application Programming and Performance Optimization	3	1

- 5.2.2 System administration training shall include presentation of system configuration documentation (cf. §5.1.1 and §5.1.2).
- 5.2.3 The Offeror shall describe how all proposed training relevant to the NWSC-3 systems will be provided (e.g., off-site classroom training, on-site training, online training, etc.).
- 5.2.4 The Offeror shall provide video recordings of hardware maintenance procedures (e.g., CRU) as part of formal training and on-demand.
- 5.2.5 The Offeror shall grant to UCAR the right, at its discretion, to record training presentations from the Offeror for UCAR-internal use thereafter.

## 6 Delivery and Acceptance Specifications

Testing of NWSC-3 systems shall proceed in three steps: pre-delivery, post-delivery, and acceptance. Each step is intended to validate a system and support subsequent activities



leading to placing the systems into production. A sample acceptance test plan is included in the UCAR RFP000074 Attachment 4F Sample Subcontract Schedule F Acceptance Criteria and Testing. Offerors should include with their proposal any necessary or suggested changes to the testing described in Schedule F. A detailed acceptance test plan will be developed subsequent to Subcontract award.

### **6.1 Pre-delivery Testing**

CISL and Offeror staff shall perform pre-delivery system assembly and testing, including a Factory Trial, as described in UCAR RFP000074 Attachment 4F Sample Subcontract Schedule F Acceptance Criteria and Testing. The pre-delivery testing shall be performed at the Offeror's facility on the hardware to be delivered. Any limitations for performing the pre-delivery testing must be identified in the Offeror's proposal. During pre-delivery testing, the successful Offeror shall:

- a) Demonstrate system RAS capabilities and robustness, using simple fault injection techniques such as disconnecting cables, powering down subsystems, or installing known bad parts.
- b) Demonstrate functional capabilities on each segment of the system built, including the capability to build applications, schedule, and run jobs. The root cause of any application failure must be identified.
- c) Provide a file system sufficiently provisioned to support the suite of acceptance tests.
- d) Provide on-site, and remote access if necessary, for NCAR staff to monitor testing and analyze results.
- e) Instill confidence in the system's ability to conform to the Subcontract's commitments.

### **6.2 Site Integration and Post-delivery Testing**

CISL and Offeror staff shall perform site integration and post-delivery testing on the fully delivered system, as described in UCAR RFP000074 Attachment 4F Sample Subcontract Schedule F Acceptance Criteria and Testing.

During post-delivery testing, the pre-delivery and Factory Trial tests shall be rerun on the full system. Where applicable, tests shall be run at full scale.

Some limitations may exist, post-delivery, for Offeror access to the system (both at the NWSC and via remote access). All access to UCAR facilities and systems shall be coordinated through the NWSC facility's security staff and CISL IT staff, respectively.

### **6.3 Acceptance Testing**

CISL and Offeror staff shall perform onsite acceptance testing on the fully installed system, as described in UCAR RFP000074 Attachment 4F Sample Subcontract Schedule F Acceptance Criteria and Testing. The Offeror shall provide any suggested modifications to the sample acceptance test plan provided in the RFP's Attachment 4F with the Offeror's proposal.

The systems shall be subject to functionality, resilience, performance and availability testing and meet the criteria specified in the Subcontract's negotiated Schedule F, and shall demonstrate that the delivered systems conform to the Subcontract's negotiated Statement of Work.

## 7 Risk Management and Project Management

The Offeror's proposal shall provide a commitment to NWSC-3 project management, based upon the sample project management plan included in UCAR RFP000074 Attachment 4G Sample Subcontract Schedule G Project Management Requirements, that addresses the following:

- 7.1.1 The Offeror's project management approach and proposed staffing for the delivery, installation, and acceptance of the NWSC-3 production and test systems.
- 7.1.2 A risk management strategy for the proposed system in case of technology problems or scheduling delays that affect technology or component availability or the achievement of performance targets in the proposed timeframe. It shall also include the impact of any substitute technologies on the overall architecture and performance of the proposed system. In particular, the Offeror shall address the technology areas listed below.
  - a) Processor(s) and GPU(s)
  - b) Memory
  - c) High-speed interconnect, both hardware and software
  - d) Storage subsystem, both hardware and software
- 7.1.3 Any other high-risk areas and accompanying mitigation strategies for the proposed system or delivery of proposed services.
- 7.1.4 A clear plan for effectively responding to system performance deficiencies, software and hardware defects and system outages, and documentation describing how problems or defects will be escalated.
- 7.1.5 Any additional capabilities including the Offeror's:
  - a) Ability to produce the proposed system and maintain it for the life of the platform
  - b) Ability to achieve the target quality assurance, reliability, and availability goals
  - c) In-house testing and problem diagnosis capability, including hardware resources at appropriate scale

## 8 References

[1] Cheyenne System Information: <https://www2.cisl.ucar.edu/resources/computational-systems/cheyenne>

[2] Cheyenne Workload Study: [https://www2.cisl.ucar.edu/sites/default/files/Cheyenne\\_Workload\\_Study\\_2019.pdf](https://www2.cisl.ucar.edu/sites/default/files/Cheyenne_Workload_Study_2019.pdf)

[3] NCAR GLADE Integration Guide:

[https://www2.cisl.ucar.edu/sites/default/files/Glade\\_Overview\\_2019.pdf](https://www2.cisl.ucar.edu/sites/default/files/Glade_Overview_2019.pdf)

[4] NIST National Vulnerability Database (NVD): <https://nvd.nist.gov/>

[5] NCAR HPC Benchmarks Website: [https://www2.cisl.ucar.edu/hpc\\_benchmarking](https://www2.cisl.ucar.edu/hpc_benchmarking)

[6] NWSC-3 RFP Website: <https://www2.cisl.ucar.edu/resources/nwsc-3>