NIST Creating Helpful Incentives to Produce Semiconductors for America
NIST CHIPS 1000-2 ipd

Building a Metrology Exchange to Innovate in Semiconductors (METIS)

A Vision for the CHIPS Metrology Program Data Exchange

Initial Public Draft

This publication is available free of charge from:
https://doi.org/10.6028/NIST.CHIPS.1000-2.ipd

NIST
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

NIST Creating Helpful Incentives to Produce Semiconductors for America
NIST CHIPS 1000-2 ipd

Building a Metrology Exchange to Innovate in Semiconductors (METIS)

A Vision for the CHIPS Metrology Program Data Exchange

Initial Public Draft

This publication is available free of charge from:
https://doi.org/10.6028/NIST.CHIPS.1000-2.ipd

December 2023

U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
Laurie E. Locascio, NIST Director and Under Secretary of Commerce for Standards and Technology

NIST Technical Series Policies
Copyright, Use, and Licensing Statements
NIST Technical Series Publication Identifier Syntax

Publication History
Initial public draft

How to Cite this NIST Technical Series Publication
CHIPS for America (2023) Building a Metrology Exchange to Innovate in Semiconductors (METIS). (National Institute of Standards and Technology, Gaithersburg, MD), NIST Creating Helpful Incentives to Produce Semiconductors for America (NIST CHIPS) 1000-2 ipd. https://doi.org/10.6028/NIST.CHIPS.1000-2.ipd

Contact Information
research@chips.gov

Public Comment Period
December 14, 2023 –February 16, 2024

Submit Comments
research@chips.gov
You may use the comment form at https://www.nist.gov/programs-projects/metis to organize your comments.

Abstract

There is an immediate need to make NIST research funded through the CHIPS Metrology Program available in a manner that guards intellectual property, protects U.S. security interests, is aligned with the approach used by NIST for access to research results, and is self-sustaining to meet future needs. Establishing a data exchange ecosystem will meet that need, giving stakeholders access to CHIPS Metrology research results and serving to catalyze breakthroughs in U.S. semiconductor manufacturing. We call this data exchange concept "METIS"—Metrology Exchange to Innovate in Semiconductors—after Metis, the Greek goddess of innovative ideas, good counsel, skill, and craft. The METIS concept leverages and builds upon currently existing data management systems and processes at NIST, an organization uniquely qualified to both produce and manage leading metrology research and technical data products. By designing the data ecosystem around and for research needed by the public, industry, and the scientific community, METIS serves as a virtual platform for curation of microelectronics research data and tools with security and controls to enable the final products to reach their intended recipients.

Keywords

circuits; data-sharing platform; manufacturing; materials; microelectronics; semiconductors; standards

Table of Contents

Preface

The CHIPS Metrology Program is one of the four major research and development programs in CHIPS for America at the National Institute of Standards and Technology (NIST). It is a collaborative program that brings together CHIPS staff members and NIST researchers with stakeholders from industry, other government agencies, and academic institutions to address measurement challenges related to microelectronics manufacturing. Through this collaboration, the CHIPS Metrology Program expands upon NIST's strong track record supporting the microelectronics technology and manufacturing ecosystem by developing, advancing, and deploying measurements, standards, reference materials, and best practices. To learn more about the CHIPS Metrology Program and CHIPS for America, visit https://www.chips.gov/metrology-program and https://www.chips.gov respectively. To learn more about NIST, visit https://www.nist.gov.

This document describes a data-sharing platform, or data exchange, to ensure that the direct results of scientific research funded through the federal CHIPS Metrology Program are made available to and are useful for the public, industry, and the scientific community.

Acknowledgments

This report was prepared through the collaborative insights of the following individuals representing CHIPS for America, NIST Laboratory Programs, and NIST Office of Information Systems Management:

Alden Dima
Aric Sanders
Blair Heiserman
David LaVan
Gretchen Greene
Hannah Brown
James Fowler
John Messina
Katherine Sharpless
Marla Dowell
Michael Bartock
William Osborn
Yuri Ralchenko

Executive Summary

The metrology provision of the CHIPS Act of 2022[1] states, "The Director of the National Institute of Standards and Technology shall carry out a microelectronics research program to enable advances and breakthroughs in measurement science, standards, material characterization, instrumentation, testing, and manufacturing capabilities that will accelerate the underlying research and development for metrology of next-generation microelectronics and ensure the competitiveness and leadership of the United States within this sector." In response, the CHIPS Metrology Program was established to fulfil these legislative requirements, leveraging NIST's proven measurement science expertise to conduct research on measurements that are accurate, precise, and fit for the production of microelectronic materials, devices, circuits, and systems.

The CHIPS Metrology Program is committed to ensuring that the direct results of federally funded scientific research are made available to and are useful for the public, industry, and the scientific community. The dissemination and exchange of data, models, and other data products convey the outcomes of world-leading microelectronics research to the marketplace, enabling and supporting America's security and commercial competitiveness.

There is an immediate need to make NIST research funded through the CHIPS Metrology Program available in a manner that guards intellectual property, protects U.S. security interests, is aligned with the approach used by NIST for access to research results,[2] and is self-sustaining to meet future needs. Establishing a data exchange ecosystem will meet that need, giving stakeholders access to CHIPS Metrology research results and catalyzing innovative breakthroughs in U.S. semiconductor manufacturing.

We call this ecosystem concept "METIS"—Metrology Exchange to Innovate in Semiconductors—after Metis, the Greek goddess of innovative ideas, good counsel, skill, and craft.[3] The METIS concept leverages and builds upon currently existing data management systems and processes within NIST, an organization uniquely qualified to both *produce and manage* leading metrology research and technical data products. By designing the data ecosystem around and for research needed by the public, industry, and the scientific community, METIS shepherds the research process from the start and provides security and controls to enable the final products to reach their intended recipients. This concept also accelerates the development of a data ecosystem and exchange, as many elements already exist at NIST and need not be built from scratch.

The CHIPS Metrology Program is one of the four research and development programs at CHIPS for America. Other programs include Manufacturing USA, the National Advanced Packaging Manufacturing Program, and the National Semiconductor Technology Center (NSTC). The NSTC vision[4] calls for the establishment of the Design Enablement Gateway. The NSTC is envisioned as an independent public-private consortium, with which the CHIPS Metrology program will partner closely. This partnership will evolve and future METIS improvements will need to take this into account.

1 Introduction

In December 2020, as part of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (NDAA), Congress passed into law funding for programs from the bipartisan CHIPS for America Act. The NDAA authorized the Department of Commerce (DOC), the Department of Defense (DoD), and the Department of State (DOS) activities to develop onshore domestic manufacturing of semiconductors critical to U.S. competitiveness and national security. Just 12 % of semiconductor chips currently produced globally are manufactured in the U.S., a 37 % decrease since the 1990s. The decrease in manufacturing capacity does not reflect consumer and commercial semiconductor chip needs, as the U.S. market for logic chips is in the tens of billions of dollars. The CHIPS Act of 2022 provided appropriations needed to implement the programs currently authorized by the bipartisan CHIPS for America Act.

The CHIPS and Science Act of 2022[5] (15 USC §4645) calls for the director of the National Institute of Standards and Technology (NIST) to “carry out a microelectronics research program to enable advances and breakthroughs in measurement science, standards, material characterization, instrumentation, testing, and manufacturing capabilities that will accelerate the underlying research and development for metrology of next-generation microelectronics and ensure the competitiveness and leadership of the United States within this sector.”

In September 2022, NIST published a report titled “Strategic Opportunities for U.S. Semiconductor Manufacturing.”[6] The report identified seven grand challenges that require critical attention from a metrology perspective to achieve the future stated vision of a U.S.-led global semiconductor industry. Each of the seven grand challenges features a set of 32 path forward elements that describe potential strategies for addressing identified challenges. These elements reflect extensive outreach to academia, the manufacturing industry, and government partners.

NIST has earned and maintains a reputation as an objective, unbiased, trusted partner of U.S. industry in furthering the nation’s economic and technical goals. NIST has a track record of serving as the neutral host for numerous high-value technical collaboration efforts among U.S. businesses, academia, and other federal agencies. Examples of successful multilateral efforts include the National Cybersecurity Center of Excellence (NCCoE),[7] the Agile Robotics for Industrial Automation Competition,[8] the National Advanced Spectrum and Communications Test Network,[9] and the NextG Channel Model Alliance,[10] along with the numerous measurement and evaluation efforts in NIST’s AI program.[11] NIST was a leader in evolution and improvement of GSA’s FEDRAMP process, shepherding authorization for many well-known cloud services, and has helped other agencies achieve authorizations for services they sought to certify in FEDRAMP. NIST hosts and maintains multiple enclaves in well-known cloud service providers for the NCCoE, NIST’s National Vulnerability Database,[12] cybersecurity services that NIST operates on behalf of the entire Department of Commerce, services that NIST supports for the entire Federal government,[13] and, finally and notably, NIST developed and hosts its Science Data Portal.[14]

2 Stakeholder Needs

The CHIPS Metrology Program is committed to ensuring that the direct results of federally funded scientific research are made available and usable by the public, industry, and the scientific community. METIS (NIST's Metrology Exchange to Innovate in Semiconductors) will provide stakeholders with access to CHIPS Metrology research results and serve to catalyze innovative breakthroughs in U.S. semiconductor manufacturing. Primary stakeholders include microelectronic suppliers, manufacturers, product developers, and system engineers in academia and industry who design, fabricate, and test semiconductors, associated component parts, and their supply chains.

The semiconductor industry places the highest value on fully vetted data. The CHIPS Metrology Program will generate data (including Standard Reference Data (SRD)[15]), measurement methods, reference process design kits (PDKs), reference materials, standards, and publications. METIS could also collect and disseminate custom products to multiple parties for challenging measurements, host results of comparisons from multiple links in the supply chain, and allow access to managed data from external sources. Data in METIS will be shared with intellectual property rights in mind and will ensure that all data is reviewed and approved for sharing with authorized parties. The industry would benefit greatly from using METIS as a single-stop source for resources that already exist, such as research-grade test materials (RGTMs), SRD for extreme-ultraviolet (EUV) emission spectra, the Nanolithography Toolbox,[16] and relevant NIST-authored publications.

Semiconductor manufacturing data is held very closely. For example, leading-edge circuit design intellectual property (IP) is a trade secret for every manufacturer and is valued at more than $300 million. As part of the CHIPS Metrology Program's research portfolio, NIST researchers may partner with individual entities for specific research projects; manufacturing and metrology data from devices not yet in high-volume manufacturing will likely be covered by restrictive arrangements like nondisclosure agreements (NDAs) and Cooperative Research and Development Agreements (CRADAs). Some software and data may be subject to International Traffic in Arms Regulations (ITAR). The METIS Operations Concept considers the different types of data and use cases, measurement methods, reference process design kits (PDKs), reference materials, standards, and publications. METIS could also collect custom products and disseminate them to multiple parties for challenging measurements, provide results from comparisons from multiple links of the supply chain, and access managed data from external sources. Data in METIS will be shared with intellectual property rights in mind and METIS will ensure that all data is vetted for sharing with authorized parties.

3 Operations Concept

METIS will provide a secure operational environment for managing and disseminating digital products resulting from the CHIPS Metrology research portfolio such that stakeholders can search, identify, and access a rich suite of microelectronics-related data, generated software tools and models, and a semiconductor knowledge base to facilitate the exchange, transformation, classification, and use of semiconductor resources from a variety of subcommunity perspectives. The CHIPS Metrology Program's portfolio of projects and those project objectives for product development, along with stakeholder needs, will determine the basis for the requirements and design of METIS. In broad strokes, METIS will store (and share when appropriate) four types of information. We will:

- Develop a CHIPS collection within the existing NIST Science Data Portal through which appropriate data will be made freely available to the public.
- Expand as necessary the capabilities of NIST business systems to offer additional saleable products (calibration services, SRD, Standard Reference Materials (SRM), and reference material categories).
- Extend the capability of the existing NIST system to provide restricted access to certain types of data, requiring users to register before access is provided. The system will be capable of providing audits on inputs, access, and downloads.
- Provide storage for sensitive or proprietary information, including FIPS 199 High impact data. The full scope of the CHIPS Metrology Program is broad, and individual laboratories will need to manage research workflows, including data acquisition from scientific instrumentation, models and simulations, derivation of working data, and sample processing histories. Digital products will be derived through processing, comparisons with statistical analysis, and critical evaluation. Products will be preserved and curated in a repository, protected according to FIPS requirements and agreements with all stakeholders using appropriately categorized impact levels and applying corresponding secure access controls. The high-quality scientific and technical products will be disseminated in a variety of formats to stakeholders using FAIR[17] practices. While these requirements are similar to those of other NIST laboratory programs that generate data related to a CRADA or other formal agreement, NIST currently lacks an enterprise solution to provide for sensitive or proprietary information, including FIPS 199 High impact data (see Figure 1).

Partnering organizations will also contribute data, process models, and code to the CHIPS Metrology Program, requiring a secure means for the transfer and exchange of digital assets. Individual users will be registered to obtain access to METIS service interfaces for input or access. When appropriate, our external partners will also be able to participate in co-development of specific platform systems or components. This will require the ability to accommodate hybrid solutions that mix multiple open-source and commercial solutions while securely integrating with government network infrastructure. Additionally, the METIS system should include auditing capabilities such that user access instances, submissions, and downloads are logged.

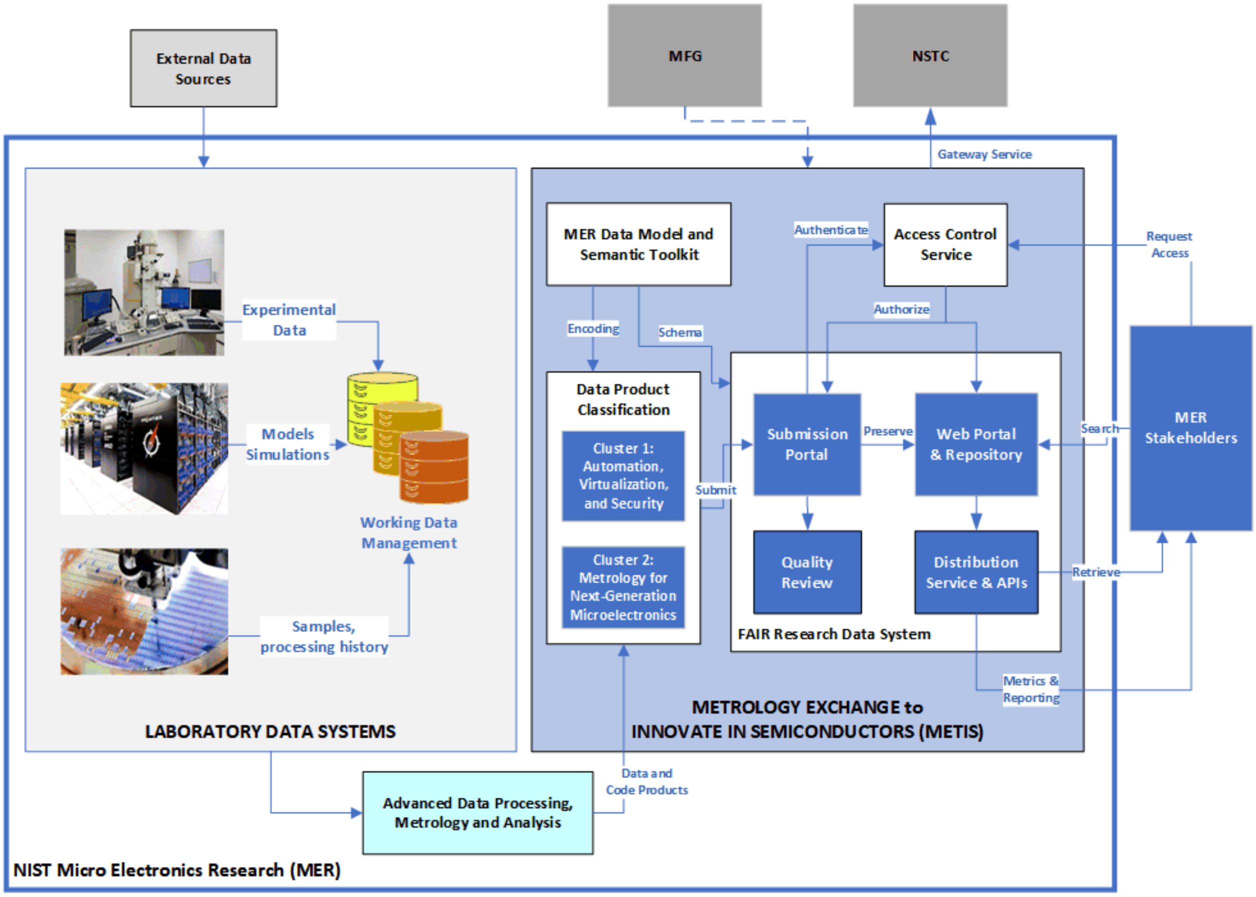

Figure 1. NIST Microelectronics Research (NIST MER) with METIS Functional Architecture Concept. NIST has a vibrant ecosystem of microelectronics research. Laboratory data systems are the systems for collecting, sharing, and processing working data. Individual systems are described in data management plans. The CHIPS Metrology Program will provide support for NIST MER activities; outputs from NIST MER will be made accessible through METIS. The purpose of this document is to describe METIS and identify NIST IT infrastructure gaps that serve as a barrier to deploying METIS. Some of these gaps are specific to CHIPS Metrology needs; some gaps stem from institutional needs for consistent information access to NIST research outcomes required by directives related to public access to NIST research.

Due to the complexity of workflow, implementation will require a phased approach and prioritized key deliverables to successfully achieve program milestones. It will be imperative that the NIST Risk Management Framework (RMF) is followed throughout the development and operation of METIS to ensure proper use of the system. The products and services will need to be categorized according to FIPS 199 so that systems storing and providing access have appropriate security controls in place. Once categorized, the systems will be secured to those standards while applying the security systems engineering principles laid out in NIST Special Publication 800-160, Volume 2, Developing Cyber-Resilient Systems: A Systems Security Engineering Approach.[18]

3.1 CHIPS Metrology Program Product Types

Two cluster areas identified in the CHIPS Metrology Program workshops provide general categories for expected outputs produced from the ten Metrology Program research focus areas.[19] For the purpose of this document, these are referenced as a basis for the research products that will be contributed to METIS holdings. Cluster 1, *Automation, Virtualization, and Security*, will generate products from advanced and validated models derived from proprietary NIST MER process data. Cluster 2, *Metrology for Next-Generation Microelectronics*, will generate metrology and calibration method products from proprietary device and materials characterization using advanced metrology methods. The original source material and information will most likely be proprietary or covered under a CRADA, prohibiting dissemination; however, NIST MER cluster area products will be developed for the purpose of dissemination and use by the intended stakeholder communities.

The NIST MER research products will be curated within METIS in the form of established digital resource types representing RGTMs, NIST Reference Materials (RMs), SRMs, and SRD in addition to new types that may be defined during cluster output development. These aggregate types will further optimize product discovery, mining, and access within METIS. Sources will include rich metadata descriptions with one or more components: data files, software (code), etc. The various product structures and formats will be constructed with the goal of helping end users process and/or analyze the information. Advanced composite product types planned for METIS are part of a longer-term ease-of-use vision to enable external applications to work with containerized digital payloads.

While METIS is envisioned to support dissemination, there will be different levels and classifications for access. Each digital product asset (data, code, tool) will be appropriately tagged and managed according to procedural requirements for specified levels of controlled access and sensitivity, e.g., proprietary data handling, access controls to support authorization, and possible licensing or terms and conditions. The access control functions will provide the technical framework for product visibility and dissemination.

Source materials and digital artifacts from external participants for the purpose of interlaboratory studies used in characterization of RGTMs may result in additional requirements such as product anonymizing, structuring, and limited access to products in the comparative stage of development. METIS requirements development will factor in these workflows as they relate to the functional areas defined below.

3.2 METIS Functionality

The fundamental capabilities for METIS will center around the management and dissemination of products generated from the NIST MER program cluster areas. These are described within the core functional areas of this section. The interfaces between laboratory data workflows, external partner systems, and METIS will require clear technical provisions for managing the security and protections of these high-value digital assets. The NIST MER program will have immediate access to NIST infrastructure services, frameworks, and tools that uniquely provide these core functions; however, the architecture of the METIS system will also be flexible to adapt its solution to optimize the use of cluster-derived products for the benefit of the stakeholder community.

3.2.1 Input to the METIS System

The process for submitting products to the METIS system will involve integrated tools and a prescription for required organization, structure, and steps. Additionally, there will be aspects of the system that allow for customization and flexibility. NIST MER will have access to solutions such as those described in the section on Current Situation and services adapted to meet mission requirements. It is envisioned that the submission to METIS will be completed through a user-oriented application portal, designed to support the product types resulting from NIST MER cluster activity. Metadata entry, uploading of files, and linkage to relevant information are supported through ingest. Qualification process[es] (technical, policy, security), will provide a form of gatekeeping and ensure the products are meeting requirements for stakeholder readiness. Approved METIS product submissions will be processed for ingest into the designated repository system.

Submissions may also be supported through secure application programming interfaces (APIs), which will, in turn, validate and provide appropriate mechanisms for repository ingest. These workflows may include receipt of external and or remotely generated products and, depending on required checks and balances, orchestrated processes for vetting of these submissions may be performed. API services are also key to enabling workflow automation. Automation, including moderated workflows, can facilitate controlled and secure product ingest such as those from calibration pipelines, analytical tools, dynamic data streams, or simulations.

METIS will enable the CHIPS Metrology Program to manage data product versions and curate holdings associated with evolving cluster activities. The intake processes will need to support change management and services to curate product holdings, including deletion and modification.

3.2.1.1 Product Classification Routing

There are different levels of categorization of the resources entered into METIS. As briefly described in the products section, resource types and associated access levels will be assigned. The technical processes for product categorization routing will support both assignment and identification of the types and access level for submission to the METIS system. Access-level management will apply appropriate controls to meet or exceed requirements for operational security and data protection. By applying cybersecurity controls, the processes will monitor and measure the security of the system.

3.2.2 NIST MER Metadata and Semantic Models

Researchers need modular data models that capture their data and metadata in community-developed templates using reusable data types. In terms of the cluster-developed products, it is expected the scheme used to create these data models will support the structuring of measurement and modeling outputs into shared model representations. This will help ensure that the data can be easily understood and utilized by different systems and stakeholders. Services for mapping, extraction, and translation of working data outputs into a NIST MER data model will be a key part of product development. These techniques are widely accepted as best practices in data science and will become part of the METIS data model and semantic toolkits.

METIS services will use standardized methods for encoding, interpreting, and transforming data and metadata. This will include openly defining the common metadata format with a formalized schema and implementing an extensible model with separated generic and domain-specific metadata. Generic metadata such as identity, basic types, providers, role, content, and access provides a clear understanding of the resource and its context without being mired by fine grain domain-specific information. This enables varying levels of model validation, promotes interoperability, allows for evolution of models without disrupting existing services depending on core metadata, and makes it easier to integrate with other systems.

The metadata model will provide type-specific metadata for different types of resources and allow individual resources to belong to multiple types or a domain collection. This will enable the model to be applied across domains. The metadata model will also include a controlled vocabulary to provide a consistent and standardized means for identifying attributes of objects in the domain. This will further facilitate comprehension across different systems.

3.2.2.1 Persistent Identification

It is important to assign unique persistent identifiers (PIDs) when managing products and their associated metadata. The forms of PIDs used will depend on the resource type and constituent components of the product. Standard forms of PIDs, currently implemented in the NIST research data infrastructure, will be incorporated into METIS. This will help ensure that products and their associated metadata can be uniquely identified and easily connected for use.

In addition to assigning PIDs to data and metadata, the common metadata format itself will have a unique identifier associated with it. This will help ensure that the metadata format can be easily identified and utilized to account for changes, and that metadata from different sources can be easily integrated.

3.2.2.2 Model Granularity and Extension

It is important to use a combination of standardized components to ensure consistency and interoperability when designing custom data formats. These components will include community-developed templates that describe experiments or simulations, as well as low-level reusable data types that encode data values and metadata fields in a standard way. By using standardized components, custom data formats can be developed efficiently and can be more easily integrated with other systems.

In addition to using standardized components, the metadata model for describing data resources will be designed to leverage both internal and external domain areas. Best practices for extensibility, such as the NIST Extensible Resource Datamodel,[20] will be followed to ensure that the metadata model can be easily augmented as needed. This will allow for a more comprehensive and flexible metadata model that can be adapted to different types of data resources and domains.

3.2.2.3 Provenance

Comprehensive data provenance ensures that the origin and lineage of the data are established. Appropriate provenance can be achieved by including the original authoritative copy, version identification, and the provenance of data derived from other sources. Timestamping will also be implemented for all data to enable proper tracking and monitoring of changes. It is also important to provide provenance information for software descriptions, custom code, instrument configuration, and data acquisition descriptions. By following best practices and community standards, product digital assets can be stored and preserved in a sustainable and efficient manner.

3.2.3 Repository and Services

The METIS repository will serve as the persistent component to manage storage and integrity of NIST MER products over time. There are various types of persistent formats (file systems, databases, services, etc.) to account for the complexity of product structure. This function of METIS can leverage shared and sustainable framework environments within the NIST infrastructure which have been successfully demonstrated for use in other disciplines. The repository is at the heart of METIS and provides capabilities supporting product structure and additionally microelectronic specific semantic definition, I.e., meaning of data, relevant to NIST MER cluster activity and the community. It lends itself as rich resource for machine learning and human oriented utility of NIST MER products.

The repository and related services will provide an integrated set of tools for researchers to store and access the products generated in the MER. The repository solution environment most likely will require a suite of technologies to allow for flexibility in hosting the data models designed to represent the cluster science.

3.2.3.1 Storage (files and metadata) and Preservation

All required product digital assets will be stored and preserved in METIS using best practices and community standards. This includes data files, metadata, code and software, e.g., calibration code sets, and related digital artifacts. Products will be persisted using standard packaging, following the current practice of the Open Access to Research preservation format, BagIt, to achieve viable sustainability of the products. This form of implementation allows for machine readability and serviceability through APIs and is technology agnostic. The package will serve as a fundamental unit for dissemination of data through services.

The product storage will also implement processes for backup, safe storage, and integrity checking. Further administrative processes and policy will be defined and implemented to manage maintenance of the products such as identification of orphan and invalid datasets or removal of data. These processes will need to account for standards in data publication persistence in addition to procedural requirements for NIST MER and NIST research data infrastructure.

3.2.3.2 Versioning, Change Management

Curation of products in METIS requires capabilities for making changes, either in the creation of new products or modifying the composition of the product in relation to evolving research output or stakeholder usability requirements. Support for change management will include both tools as well as the implementation of versioning. The submission system and underlying services will support this versioning capability for both minor updates as well as major structure changes, with supporting workflow and policy. Access to previous versions will be possible per access-controlled measures. NIST has implemented this form of change management in the current data systems, which demonstrates a unique feature for ongoing maintenance and viability of stored data products.

3.2.3.3 Integrity Checking

Integrity checking is a critical capability of the storage and operation of METIS. This comes into play both on data ingest and preservation, as well as monitoring and dissemination. The ingest process will validate common metadata for both structure and format. A metadata validation service will be integrated into the system, yet also will be available for use independently. There will be multiple touchpoints for working with METIS metadata and thus having independent services for verification and validation will be critical.

Integrity checking is also inherently required for digital asset management. Services and processes for guaranteeing the integrity of METIS will be implemented; NIST’s current system provides these types of services to safeguard products from system failures and cybersecurity issues.

Disseminated data products will include—in addition to metadata structure validation—the appropriate hash values to further support validation that the products in METIS are accurate and well-formed. The distribution of data will provide means for accessing these hash values, per access control constraints, and support integrity checking in both operation and end-user client use.

3.2.4 Search and Discovery of NIST MER Research Products and Tools

Searches for NIST MER research products will commonly be performed through a web user interface. A web portal will provide a point of entry for stakeholders to search, filter, explore, and request access to data and related resources. This search portal shall include many main features including text, fields, and categorical selections. Many of these are readily available in many expert NIST research portal systems and may be adapted to support the METIS resource collection. Advanced search capabilities such as auto-suggest and query supporting functionality will provide decision-aided features to help direct users to more relevant product information.

Categories of search will include generalized resource types, data, code, and will also allow for more discipline-focused search based on a taxonomy of METIS products.

3.2.4.1 Stakeholder Use Cases

Stakeholder use cases will inform the requirements and development of METIS search functionality. Engagement with the various discipline communities both operating internally and externally to NIST MER will be reoccurring, as discovery with new research areas emerge. Search will allow for data discovery and sharing systems to specialize their capabilities to match specific sub communities.

A METIS account registration will be enabled as support management of permission levels and associating users with specific access functionality. Advanced capabilities for user profiles will be considered with long-term goals to provide stakeholder capabilities for storing access history, managing group access, and saving information related to the use of the system.

3.2.4.2 Gateway to Sensitive Data

Product search will include navigation for access to different levels of sensitivity for data. This includes directed navigation to the appropriate user interface location and/or gateway services. It is anticipated that search may implement restrictions placed on access to products. Gateway services will determine based on user accounts or profile what search and access capabilities will be made available. These services provide the technical solution to manage search based on access level (low, moderate, or high), product type, and specified restrictions.

3.2.4.3 Search Help

User support is an important feature of METIS and will help people understand use of the system (See Guidelines section), in addition to quick search. One common feature coupled with search is to direct users to important supporting capabilities. This will include quick links for Fair Use and how to cite the products in their works. The search capabilities will include providing direct access to Help and Support of the system.

3.2.5 Access to METIS Resources

Several functional components will play a role in access to the products and, as mentioned throughout this document, careful attention will be made to safeguard access to sensitive data while simultaneously providing capabilities that optimize interoperability and performance.

An access control system will manage user requests for access, adhering to NIST SP 800-63 Digital Identity Guidelines. This system will comprise services for authentication, authorization, profiles, and group access control. The NIST MER product type will determine the required access controls. Services designed to work with these controls will be implemented for managing ingest to the appropriate repository location, access for search and product viewing, and dissemination of products.

The existing NIST systems have implemented public access services and restricted access workflows to data. These serve as a template for design of these capabilities in METIS. Proprietary data access may take advantage of compartmentalized persistent locations in combination with a technical gateway.

For the generation of NIST MER SRD, systems and services are already in place to manage access and distribution for both free and fee-based service models.

Overall, the access control system for METIS will apply identified security controls from NIST SP 800-53 to protect High impact data. These also will account for specific forms of restriction including export-controlled products.

3.2.5.1 Distribution Services

Authorized requests for access will use standard application programming interfaces (APIs) that operate between the portal search and repository system to retrieve and deliver products to end users. These services will consider requirements for capacity, structure, synchronous and asynchronous forms of delivery, and follow guidance from NIST SP 800-171 Protecting Controlled Unclassified Information in Nonfederal Systems and Organizations to protect information shared outside of federally controlled systems, where applicable. These services also will use standard payload syntax, schema, and semantic representations to provide interoperability between tools, services, and organizations operating with the MER. As an example, secured distribution services may support gateways for exchange between the METIS platform, consortium members, and the NSTC.

3.2.5.2 Usage Metrics

Statistics on usage of the METIS system and specific products or tools will largely determine the impact these have to the stakeholder community. Metrics are key performance measures that benefit the NIST MER product creators, stakeholders, and implementation of METIS. Depending on the level of granularity of metrics, they will help formulate reporting of the performance of various data and software systems, tools, as well as the productivity of the NIST MER instrumentation and technology. These usage measures can also inform the NIST MER as to stakeholder extent, uniqueness, and number of collaboration activities.

3.3 Guidance / Tools on how to use METIS

Documentation and tools that describe the use of METIS will be accessible to CHIPS Metrology Program participants. These will include guidance and procedures for all aspects of the system functionality including submission, access, curation, and use of services and tools. With the expectation that not all products stored in METIS will be openly public, permissions and access will need to be clearly indicated throughout, along with guided processes for handling of requests.

Users and partner organizations building applications to interface with METIS may require more range in utility. Expert staff and user support processes will need to accommodate human communications to facilitate these engagements.

User support design will occur in parallel with the technical implementation to ensure that guidance is addressed from the beginning to reduce failures, optimize throughput, and collect feedback for enhancements to improve upon the system performance. For robustness in these support areas, METIS will adopt a strategy and implementation for managing and tracking issues as they occur throughout the phases of operation.

3.4 METIS Implementation Timeline

The planning, design, development, testing, and phased implementation of METIS and other supporting resources can occur in the following sequence:

Table 1. Implementation Timeline

<table>
<tr><th>System Elements ↓</th><th>Initiation</th><th>First 6 Months</th><th>6 to 12 Months</th><th>Second Year</th><th>Ongoing</th></tr>
<tr><td>Expertise and resources (contracted / fed staff)</td><td>♦ Establish team(s)
♦ Create SOW for contracted services</td><td>♦ Acquire vendor services
♦ Initiate design and planning</td><td>♦ Develop new system elements/enhance current systems
♦ Launch METIS by end of 12 months</td><td>♦ Guide and enable design of NSTC digital resources</td><td>Enhancements and maintenance</td></tr>
<tr><td>Advanced data processing, metrology, and analysis</td><td colspan="2" rowspan="4">Plan, system requirements, design, develop, test, pilot</td><td>♦ Initial data products ready for METIS
♦ New product requirements</td><td colspan="2">Mature research projects underway with ongoing output converted to data projects and uploaded to METIS</td></tr>
<tr><td>METIS</td><td>♦ Data use/ management training and support for researchers
♦ Data model and semantic toolkit development
♦ Initial data uploads to METIS</td><td>Design exchange model for support of NSTC, partner programs, etc.
Pilot data exchange
New product metadata enhancement</td><td>Ongoing partnership with NSTC Gateway and other research exchanges</td></tr>
<tr><td>IT infrastructure (network, server, and storage)</td><td>Initial infrastructure in place for pilot research projects</td><td>Ongoing enhancements focused on “High” data management</td><td>Mature research IT infrastructure</td></tr>
<tr><td>Metrics and reporting</td><td>♦ Metric hooks into system
♦ Initial reporting by EOY</td><td>Full, auditable 12-24-month dataset for reports</td><td>Continuous improvement</td></tr>
</table>

4 Current Situation

METIS will build upon foundations that NIST has laid over the past decade via similar efforts such as the Materials Genome Initiative at NIST, the Additive Manufacturing Benchmark Test Series (AM Bench), the International Materials Resource Registries (IMRR) working group of the Research Data Alliance (RDA), the Digital NIST pilot project, the Research Data Framework project, and the NIST LIMS Roadmap. These foundations also include systems and tools that NIST has put in place to make it easy for NIST's data producers to publish their data and to make selected research data products findable by and accessible to our stakeholders.

With some exceptions (e.g., SRD, proprietary information, described below), NIST supports the dissemination of FIPS low-impact scientific outputs in publicly accessible repositories. NIST uses four interconnected systems to make data and code publicly accessible:

1. MIDAS, for "Management of Institutional Data/Digital Assets," allows NIST staff to create data management plans (DMPs) and serves as NIST's enterprise data inventory: essentially a "card catalog" of NIST data and code resources. When a record is created in MIDAS, a digital object identifier (DOI) is assigned to data or code publications. This PID can be used in associated papers, websites, etc. (Note that NIST systems support the use of standard PIDs for authors, publishers, data products, and code; systems will be expanded to allow the use of additional PIDs in support of the research security requirements of NSPM-33.[21])

2. Data can be uploaded through MIDAS to the Public Data Repository (PDR), whereby NIST's publicly available data assets are stored in the Amazon Web Services (AWS) cloud. Other public data is available through on-site servers as well as Google and Box, when authorized. Public code is stored on GitHub and, when it reaches a level of fit-for-purpose maturity, it may be published in a similar workflow as data through MIDAS and the NIST PDR. Data and code products may evolve with the research over time, and versioning is supported. The products are preserved using a platform-agnostic standard package format with hashed digital objects to support integrity checking. As part of the publication process, a web landing page is created in the PDR using standard machine-readable formats.

3. The NIST Publication System (NPS) allows managers and technical experts (internal and external) to review data and code prior to their publication. Additionally, the system is able to generate reports (e.g., numbers of publications by organization, author, topic) for authors and management.

4. The NIST Science Data Portal is the external-facing piece of the infrastructure. The core metadata in MIDAS and additional domain-specific metadata supported in the PDR are searchable through the data portal, accessible from the NIST website or through data.gov, allowing NIST customers to discover, access, use, and cite NIST data resources. Distribution of data in machine-readable, machine-actionable, and non-proprietary formats is encouraged. Metadata is available via application programing interfaces

(APIs). Discipline-specific views are being developed as is the NIST Gateway to Innovation, a single portal that will integrate search capabilities across all types of NIST research outputs (data, code, publications, reference materials, calibrations, patents) and provide contact information for staff associated with these outputs. In addition, NIST research outputs can be integrated with external communities' resources in strategic focus areas, linking to resource registries in metrology, climate, etc.

NIST's E-Commerce storefront[22] limits the availability of specific research data products to selected external partners and customers and sells NIST's products and measurement service offerings to customers via an online catalog, with shopping cart, payment, and fulfillment mechanisms.

Additionally, the capability exists to provide restricted public access to specific datasets available through the data portal and its associated infrastructure. Mechanisms for granting user access currently range from a user answering a few questions (e.g., to access value-assignment data for Standard Reference Materials) to a user being vetted by a NIST staff member who is expected to be knowledgeable about potential risks (e.g., to access forensic biometrics data).

Some of the capabilities envisioned for METIS are demonstrated by the domain-specific, publicly accessible data gateways that NIST has put in place for the Materials Genome Initiative and for the Computer Security Resource Center. If it was necessary for METIS to provide users with computing capabilities it could leverage the existing collaboration NIST has with Johns Hopkins University's SciServer team. The SciServer Manufacturing Domain is currently used for NIST's AM Bench participants to process large additive manufacturing datasets. There are other specialized platform services that can be customized and adapted for use within METIS. For example, NIST's Configurable Data Curation System[23] (CDCS) enables curation of data in a repository using predefined templates that allow interconnections for federated searches and data sharing; NIST's CDCS-based code is the basis for the International Metrology Resource Registry at BIPM and metadata curation for the AM Bench Measurement Catalog.

Guidance for assigning impact levels and performing security categorization is provided by NIST SP 800-60 Volume 1.[24] Materials designated as having High impact will not receive that designation when they are ingested by METIS. Instead, determination of the FIPS impact level for digital assets will be made at origination or when considered in the aggregate with other digital assets. We anticipate that there will be many scenarios where data acquired from NIST instruments, data reflecting process parameters, engineering design data, simulation models, digital twins, data received from external partners, and the like will be "born" with a High impact designation requiring that NIST have the infrastructure implementing the requisite technical controls on networks, interfaces, data storage, data management services, and access controls on the infrastructure as well as on the data. None of these technical controls exist at NIST on the research infrastructure where High impact data assets are likely to be originated and initially stored.

While METIS will allow the public to access certain products, it will also be able to restrict access for other assets to authorized external partners as well as to authorized internal staff. Some materials may be subject to intellectual property protections, CRADA stipulations, or other characteristics that will lead them to be characterized as having High FIPS-199 impact ratings for confidentiality and/or integrity. Accommodating materials with High impact ratings drives a whole series of system implementation requirements that are not addressed by NIST's existing platform.

Even taken together, the aforementioned tools, capabilities, and sites that NIST has deployed do not, by themselves, completely satisfy the objectives envisioned for METIS. NIST will build on these existing capabilities and on its considerable expertise to create an innovative system with a focus solely on the CHIPS Metrology Program's requirements.

4.1 Gaps

While METIS will allow the public to access certain products, it will also be able to restrict access for other assets to authorized external partners as well as to authorized internal staff. Some materials may be subject to intellectual property protections, CRADA stipulations, or other characteristics that will lead them to be characterized as having High FIPS-199 impact ratings for confidentiality and/or integrity. Accommodating materials with High impact ratings drives a whole series of system implementation requirements that are not addressed by NIST's existing platform.

This document outlines a clear vision for the implementation of METIS and describes highly successful NIST systems. However, many gaps do exist that will need to be addressed. The following are areas required to achieve the goals of our operational concept.

- NIST does not currently have a single point (e.g., portal or gateway) to compile all CHIPS Metrology Program outputs or that could serve as an access control point for collaboration. This portal will need to be developed as a component of METIS.
- Microelectronics will introduce new models that will drive the evolution of subject matter expertise and hence semantic practices. METIS development will need to be agile enough to adapt to this evolution.
- The NIST IT environment has historically handled FIPS 199 Moderate or Low impact data that is intended for publication. At this time, NIST has a single High impact system, which is currently not able to support METIS and would need to be enhanced. There is a need to provide an enterprise solution to NIST programs that generate High impact data, e.g., related to CRADAs.
- To provide appropriate protections, NIST needs processes to help provide guidance for how to identify data types and sensitivity. An expert system would assist staff in consistent identification and selection of information sensitivity of projects in support of CHIPS. Such a system would also need to provide similar guidance for downgrading of information sensitivity as the data is collated into research projects.

- NIST needs a standardized approach to provide support for High impact data with automated and maintainable processes to ensure protections are applied through the system lifecycle. This requires upgrades to the existing Low/Moderate environment (network, compute, storage) to support required High impact controls that must be implemented. The NIST MER program and CHIPS R&D use cases are compelling reasons for these upgrades. However, these upgrades are needed for other use cases related to NIST programs in critical and emerging technologies (e.g., advanced communications, AI, biotechnology, and quantum technologies). These upgrades also must be implemented for the other sections of the NIST environment that will support this research. Upgrades needed include endpoint systems, high-speed/High impact network, High impact storage, and High impact compute.
- The user support system will have unique needs specific to CHIPS research product delivery.
- Interfaces within the MER are needed to facilitate promotion of outputs in laboratory research data management systems to product readiness in METIS.
- Current IT challenges exist for NIST researchers, especially those with sensitive data. They are frequently confronted with concerns such as: where is it stored, how can you determine whether it is sensitive, and what if you are uncertain about its sensitivity? The NIST Risk Management Framework provides documents that can be used to identify and protect sensitive data:
    - Mapping Types of Information and Information Systems to Security Categories NIST SP 800-60[25]
    - Security Categorization – FIPS 199[26]
    - Protecting CUI in non-federal systems – NIST SP 800-171[27]

Appendix A. List of Abbreviations and Acronyms

CRADA
Cooperative Research and Development Agreement - an agreement used to formalize a cooperative research program between NIST and non-federal entities (collaborators). A CRADA must be compatible with the NIST mission; present no conflict of interest for NIST or its research project staff; and be acceptable to NIST approval authorities. Under the CRADA, the collaborator is granted the first option to take a license, on reasonable commercial terms, for any inventions made by NIST inventors/researchers or made jointly by NIST and the collaborator's inventors/researchers during the research program. Commercial products resulting from CRADA-developed intellectual property must be substantially manufactured in the United States.

DMP
data management plan - In 2013, the White House issued a memo requiring data management plans for agencies with research budgets of more than $100 million. A data management plan is a written document that describes the data you expect to acquire or generate during a research project, how you will manage, describe, analyze, and store those data, and what mechanisms you will use at the end of your project to share and preserve your data.

DOC
Department of Commerce

DOS
Department of State

EDI
enterprise data inventory

FIPS
Federal Information Processing Standards – a set of standards that describe document processing, encryption algorithms, and other information technology standards for use within non-military government agencies and by government contractors and vendors who work with the agencies.

LDS
laboratory data systems - the systems for collecting, sharing, and processing working data. Individual systems are described in data management plans.

METIS
Metrology Exchange to Innovate in Semiconductors - a platform for exchanging data products to support semiconductor research, design, engineering, and advanced manufacturing.

MIDAS
Management of Institutional Data Assets - a web-based application with two-components: a data management plan (DMP) tool and an enterprise data inventory (EDI) tool.

NDAA
National Defense Authorization Act

NIST EDI
NIST Enterprise Data Inventory - a catalog of data assets produced from NIST-funded research.

NIST MER
NIST Microelectronics Research - existing NIST microelectronics research activities as well as research activities funded under the CHIPS Metrology Program.

NSTC

National Semiconductor Technology Center - a systems-level research and development approach that connects sophisticated tools, resources, and facilities to support and extend U.S. leadership in semiconductor research, design, engineering, and advanced manufacturing. See *A Vision and Strategy for the National Semiconductor Technology Center*.[28]

NTRM

NIST Traceable Reference Material - a commercially produced reference material with a well-defined traceability linkage to existing NIST standards. This traceability linkage is established via criteria and protocols defined by NIST. Commercial reference materials producers may affix the NTRM trademark to materials produced according to these criteria and protocols.

PDK

process design kit - a set of files used within the semiconductor industry to model a fabrication process for the design tools used to design an integrated circuit.

PID

persistent identifier - a long-lasting reference to a document, file, web page, or other digital object. Most PIDs have a unique identifier that is linked to the current address of the metadata or content.

RGTM

NIST Research Grade Test Material - differs from a NIST Standard Reference Material in that it is not as highly characterized or traceable to the SI but is homogeneous and undergoing continual stability testing.

RM

Reference Material - a generic term for a material, sufficiently homogeneous and stable with respect to one or more specified properties, that has been established to be fit for its intended use in a measurement process.

RMF

NIST Risk Management Framework - a process that integrates security, privacy, and cyber supply chain risk management activities into the system development life cycle. The risk-based approach to control selection and specification considers effectiveness, efficiency, and constraints due to applicable laws, directives, Executive Orders, policies, standards, or regulations. Managing organizational risk is paramount to effective information security and privacy programs; the RMF approach can be applied to new and legacy systems, any type of system or technology (e.g., IoT, control systems), and within any type of organization regardless of size or sector.

SRD

Standard Reference Data - quantitative information, related to a measurable physical or chemical property of a substance or system of substances of known composition and structure, which is critically evaluated as to its reliability under Section 3 of the Standard Reference Data Act.[29]

SRM

NIST Standard Reference Materials - materials certified for their composition or properties, or both. These materials are used to perform instrument calibrations in units as part of overall quality assurance programs, to verify the accuracy of specific measurements, and to support the development of new measurement methods. Each NIST SRM is supplied with a Certificate of Analysis and a Materials Safety Data Sheet, when applicable.

References

[1] CREATING HELPFUL INCENTIVES TO PRODUCE SEMICONDUCTORS FOR AMERICA, Advanced microelectronics research and development, Microelectronics research at the National Institute of Standards and Technology 15 U.S.C §4656(e) (2022). http://uscode.house.gov/view.xhtml?req=(title:15%20section:4656%20edition:prelim)

[2] Policies, Directives, and NIST's Public Access Plan: https://www.nist.gov/open/policies-directives-and-nists-public-access-plan

[3] Metis was the mother of Athena and is known in mythology for equipping her offspring with the tools Athena would need when she emerged as the goddess of wisdom, warfare, and crafts.

[4] CHIPS Research and Development Office (2023) *A Vision and Strategy for the National Semiconductor Technology Center*. Available at https://www.nist.gov/chips/vision-and-strategy-national-semiconductor-technology-center

[5] CREATING HELPFUL INCENTIVES TO PRODUCE SEMICONDUCTORS FOR AMERICA, Advanced microelectronics research and development, Microelectronics research at the National Institute of Standards and Technology 15 U.S.C §4656(e) (2022). http://uscode.house.gov/view.xhtml?req=(title:15%20section:4656%20edition:prelim)

[6] National Institute of Standards and Technology (2022) *Strategic Opportunities for U.S. Semiconductor Manufacturing*. Available at https://nvlpubs.nist.gov/nistpubs/CHIPS/NIST.CHIPS.1000.pdf

[7] https://www.nccoe.nist.gov/

[8] https://www.nist.gov/el/intelligent-systems-division-73500/agile-robotics-industrial-automation

[9] https://www.nist.gov/ctl/nasctn

[10] https://www.nist.gov/ctl/nextg-channel-model-alliance

[11] https://www.nist.gov/programs-projects/ai-measurement-and-evaluation/nist-ai-measurement-and-evaluation-projects

[12] https://nvd.nist.gov/

[13] iEdison is an example of cloud services hosted by NIST that serve the entire Federal government; https://www.nist.gov/iedison

[14] https://www.nist.gov/data

[15] More about NIST's Standard Reference Data can be found at https://www.nist.gov/srd

[16] https://www.nist.gov/services-resources/software/cnst-nanolithography-toolbox

[17] Wilkinson, M., Dumontier, M., Aalbersberg, I. *et al.* The FAIR Guiding Principles for Scientific Data Management and Stewardship. *Sci Data* **3**, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

[18] National Institute of Standards and Technology (2021) Developing Cyber-Resilient Systems (Department of Commerce, Washington, D.C.), NIST SP 800-160 Volume 2, Rev. 1. https://doi.org/10.6028/NIST.SP.800-160v2r1

[19] National Institute of Standards and Technology (2023) Metrology Gaps in the Semiconductor Ecosystem: First Steps Toward Establishing the CHIPS R&D Metrology Program. (Department of Commerce, Washington, D.C.) https://www.nist.gov/document/chips-rd-metrology-gaps-semiconductor-ecosystem

[20] The NIST Extensible Resource Data Model: A Reader's Guide to NERDm Metadata. https://data.nist.gov/od/dm/nerdm/nerdm-guide.html

[21] National Science and Technology Council (2022) Guidance for Implementing National Security Presidential Memorandum 33 (NSPM-33) on National Security Strategy for United States Government-Supported Research and Development. (White House Executive Office of the President, Washington, D.C.) https://www.whitehouse.gov/wp-content/uploads/2022/01/010422-NSPM-33-Implementation-Guidance.pdf

[22] The E-Commerce Store is located at https://shop.nist.gov

[23] https://cdcs.nist.gov/

[24] National Institute of Standards and Technology (2008) Volume I: Guide for Mapping Types of Information and Information Systems to Security Categories Systems (Department of Commerce, Washington, D.C.) NIST SP 800-60, Vol. 1 Rev. 1.https://doi.org/10.6028/NIST.SP.800-60v1r1

[25] National Institute of Standards and Technology (2008) Volume I: Guide for Mapping Types of Information and Information Systems to Security Categories Systems (Department of Commerce, Washington, D.C.) https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-60v1r1.pdf

[26] National Institute of Standards and Technology (2004) Standards for Security Categorization of Federal Information and Information Systems (Department of Commerce, Washington, D.C.) https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.199.pdf

[27] National Institute of Standards and Technology (2020) Protecting Controlled Unclassified Information in Nonfederal Systems and Organizations (Department of Commerce, Washington, D.C.) https://doi.org/10.6028/NIST.SP.800-171r2

[28] https://www.nist.gov/chips/vision-and-strategy-national-semiconductor-technology-center

[29] Congressional declaration of policy. P.L. 90-396; 15 U.S.C. 290-290f (1968). https://www.nist.gov/document/srdact-2pdf