Model Context Protocol (MCP) Security

Workstream 4: Secure Design Patterns for Agentic Systems

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Contents

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Abstract

Since its emergence a year ago, MCP has rapidly established itself as the protocol for transmitting structured context between AI agents and services. Given the growing importance and attack surface of MCP and agentic systems, it is imperative that deployment specific security threats are identified and improvements are made to address the challenges and ambiguities inherent in MCP implementations. Our primary goal is to share actionable security guidance for today's MCP implementations while identifying areas where the protocol and ecosystem may need to evolve to address emerging threats. We introduce short and medium-term security implications related to MCP through the introduction of twelve core threat categories and thirty-four threats. Our taxonomy distinguishes between traditional security threats amplified by AI and MCP, and novel attack vectors. For each threat and category, we propose mitigations, defenses, and best practices for using MCP across multiple deployment scenarios including enterprise use cases. Multiple critical CVEs have been reported and incidents such as data leakage have already occurred across MCP/agentic deployments. Several examples are mentioned with links in section 2.1.

Scope

This paper focuses on the security aspects of MCP implementations, covering:

- Security analysis of the June (2025-06-18), November (2025-11-25), and 2026-07-28 MCP transport and protocol layers
- Threat modeling strategies for MCP-based agentic systems[1]
- Supply chain security considerations for MCP servers and tools
- Identity and access management challenges in agentic architectures consuming MCP endpoints
- Best practices for secure MCP deployment and operation
- Recommendations for protocol enhancements to address identified security gaps

We are collaborating with Anthropic and the MCP maintainer community to ensure our recommendations are practical and implementable. This work also coordinates with CoSAI's Software Supply Chain Security workstream to ensure comprehensive coverage of agentic system security concerns.

Anti-Scope

This paper does not address:

- Content safety, misinformation, or AI ethics concerns unrelated to security

[1]Agentic System Definition - An agentic system is an AI-powered solution that autonomously handles one or more tasks within a business workflow, replacing human decision-making nodes with automated processes that can range from simple single-task agents to complex networks of interconnected AI agents working together. The scope and sophistication of an agentic system directly correlates with both its potential economic value and operational risk, as organizations can choose to automate anything from individual yes/no decisions to entire business functions depending on their risk tolerance and automation goals.

- General AI model safety or alignment issues beyond their security implications
- Detailed implementation of specific security tools (we provide guidance, not implementation). Follow on papers will provide reference implementations and recommendations for specific mitigation controls.
- Non-security aspects of MCP performance, scalability, or functional capabilities
- Legal or regulatory compliance requirements (though our recommendations may support compliance efforts). For these matters, see the assets being created from our Workstream 3: AI Risk Governance.

Target Audience

Primary audience:

- **Security professionals and developers securing, creating or connecting to MCP servers**. This includes developers, security practitioners, enterprise architects, and organizations who are implementing, deploying, or integrating MCP servers and clients into their agentic AI systems.
- (longer term) MCP maintainers, the broader MCP ecosystem including contributors to MCP implementations and tooling, and the core protocol developers at Anthropic and beyond

Status: Draft

1. MCP Overview

MCP is an open standard developed by Anthropic and a growing open source community that provides a structured framework for connecting large language models and AI agents to external tools, data sources, and services. MCP addresses a fundamental challenge in agentic AI systems: how to enable models to access and interact with real-world resources dynamically while maintaining security and reliability through standardization. MCP simplifies AI application integration with databases, APIs, file systems, web services, and other external resources reducing the need for custom integrations for each tool or service.

MCP operates through a client-server architecture where AI applications (hosts) use MCP clients to establish connections with MCP servers that expose specific capabilities such as tools, resources, and prompts. The protocol defines standardized methods for:

- discovering available capabilities including tools or services
- invoking parametrized services
- accessing data resources

MCP supports multiple transport mechanisms including standard I/O (stdio) for local processes and Streamable HTTP for networked communications, enabling flexible deployment scenarios from local development environments to distributed cloud architectures.[2]

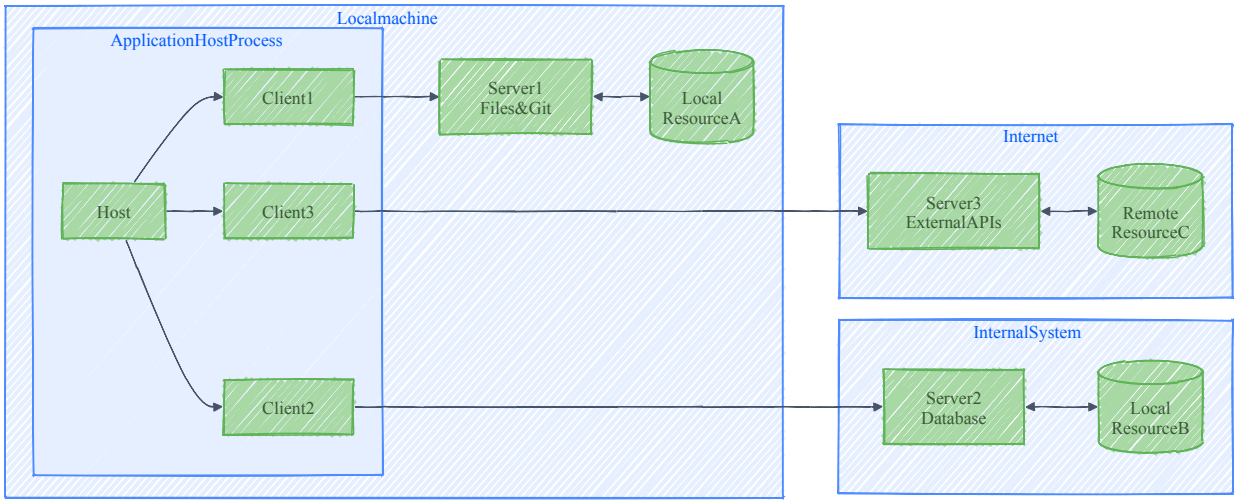
1.1 MCP Architecture

MCP follows a client-server architecture where host applications (such as AI assistants, IDEs, or workflow automation tools) use MCP clients to connect to local or remote MCP servers. Earlier MCP versions treated each client-server connection as a dedicated, stateful session that began with an initialize / initialized handshake and, for Streamable HTTP, carried an Mcp-Session-Id

[2]Server-Sent Events (SSE) over HTTP was deprecated in the 2025-06-18 revision of MCP. The 2026-07-28 release uses Streamable HTTP response streams for request-scoped events and subscriptions/listen for opted-in change notifications.

header. The 2026-07-28 release removes that protocol-level session model: each request is self-contained, carries protocol version, client identity, and client capabilities in _meta, and can be routed to any compatible server instance. Servers that need cross-call state must expose explicit handles, task identifiers, resource URIs, or other ordinary parameters rather than relying on hidden transport session state.

Communication is built on JSON-RPC, which defines the message format and protocol semantics including lifecycle management and core primitives (tools, resources, prompts, and optional extensions). The transport layer handles the delivery of these JSON-RPC messages between clients and servers, supporting stdio for local processes and Streamable HTTP for remote servers. In the 2026-07-28 release, server/discover replaces up-front initialization as the discovery mechanism for supported protocol versions, server identity, and capabilities, while extension support is negotiated through capability extensions maps.



1.1.1 MCP Deployment Patterns

MCP servers can be deployed across diverse environments with varying trust relationships and security implications. The security posture of an MCP deployment depends on several intersecting factors: where the server code originates (first-party, open source, third-party), where it executes (local machine, internal infrastructure, external cloud), and what resources it can access (local files, enterprise systems, external services).

Each deployment pattern creates distinct trust boundaries that fundamentally shape the threat model. Local deployments using stdio transport provide process-level isolation but require careful management of file system access. Internal network deployments using Streamable HTTP must consider lateral movement risks and authentication requirements. External cloud deployments introduce internet-facing attack surfaces and multi-tenancy concerns.

1. **All-Local**: The MCP client and server are co-located leveraging stdio or http transports
2. **Single-Tenant Hybrid**: The MCP client connects to a single-tenant hosted MCP server over http. The MCP client may run locally or be hosted remotely.
3. **Multi-Tenant Cloud**: MCP clients from multiple tenants connect to a shared MCP server.

These deployment patterns each carry a distinct threat model based on the trust boundaries between client and server. Threat models differ by which components are trusted or untrusted, single- vs. multi-tenant setups, and local vs. remote deployments. A deeper analysis of the security implications of each is presented in the Appendix.

2. MCP Threat Model

2.1 Threat Landscape and Methodology

As with many newly adopted technologies there are numerous examples of significant security incidents across MCP deployments.

- **Asana MCP server incident** (June 2025): A tenant isolation flaw in Asana's opt-in MCP server, present from its launch on 1 May 2025, created the potential for cross-organization data exposure. Asana identified the bug on 4 June, disabled the server from 5–17 June, and notified the roughly 1,000 affected customers directly. (Read more - Asana postmortem; Read more - BleepingComputer)
- **WordPress AI Engine plugin vulnerability** (June 2025): A missing capability check on the plugin's MCP endpoint allowed any authenticated subscriber to execute privileged commands, including user creation and option updates (CVSS 8.8). The plugin reports over 100,000 active installations, though exploitation required the Dev Tools and MCP modules to be enabled manually, which is not the default. (Read more - NVD CVE-2025-5071; Read more - changeset)
- **Supabase MCP Issue** Researchers demonstrated how prompt injection via support ticket data could cause AI tools like Cursor to expose private tables through a connected MCP server with direct database access, exploiting excessive tools and overprivilege. (Read more)

This section examines current threats through documented incidents and establishes a threat model addressing MCP's unique interdependency challenges.

2.2 Why MCP Requires a Different Approach

While there are numerous, high quality frameworks addressing AI risk (e.g. MITRE ATLAS, NIST AI RMF, MAESTRO, etc.) MCP introduces fundamentally new security considerations:

- Protocol-level authentication between AI clients and tool servers
- Dynamic capability negotiation that determines what tools AI can access
- Distributed trust relationships across multiple independent tool providers
- Explicit state, task, and context-handle management for long-lived AI workflows after removal of protocol-level sessions

Though existing frameworks are designed to assess complex multi-component systems, they assume components behave predictably according to predefined logic. MCP places an LLM, an agent whose behavior is shaped by natural language input, at the center of security-critical decisions, requiring a fundamentally different threat model.

3. MCP Threats

This framework organizes thirty-four threats to MCP deployments across twelve distinct categories, spanning the full technology stack—from foundational identity and access controls through AI-specific boundary failures to supply chain and operational visibility requirements. This model enables security teams to prioritize defenses based on the specific threats and attack surfaces relevant to their deployment. The taxonomy distinguishes between traditional security concerns amplified by AI mediation and novel attack vectors unique to LLM-tool interactions, providing clear guidance for implementing defense-in-depth strategies across the MCP

ecosystem.

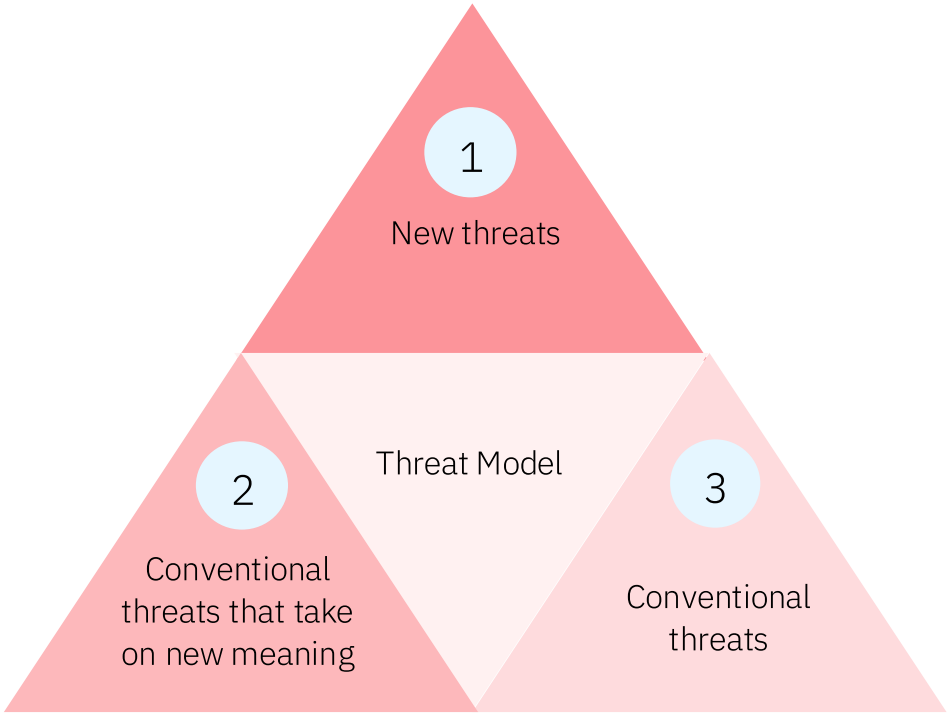


Figure 1: *Threats*

The first set of risk categories (T1–T2) covers foundational identity and access control risks critical to understanding the origins of a request and how it is being executed through the complex interactions of agents and tools. Next are threats related to input handling stemming from both traditional and AI-specific threats (T3–T4), protection of data and code confidentiality and integrity (T5–T6), and network and transport security (T7–T8). Lastly, MCP risks go beyond a protocol and reference implementation, and spans the MCP lifecycle, including how organizations use and manage MCP capabilities: managing trust relationships (T9), governing resources (T10), ensuring secure supply chains (T11), and maintaining visibility (T12).

3.1 MCP Specificity

The broad applicability and diverse deployment models and supported transports results in a large number of applicable threats. Threats are divided into three tiers:

- **Tier 1 - MCP Specific Threats (7 Threats)**: Novel risks and threats due to MCP's architecture and design decisions.
- **Tier 2 - MCP Contextualized Threats (8 Threats)**: known threats that manifest differently in MCP contexts or are amplified in MCP deployments
- **Tier 3 - Conventional Threats (19 Threats)**: security threats are broadly applicable or derive from legacy, infrastructure, or transport implementation decisions

The table below organizes the threats by category and provides a mapping to controls and mitigations, discussed next.

Threat	Threat Category	MCP Specific	MCP Contextualized	Conventional Security	Control and Mitigation
MCP-T1	Improper Authentication and Identity Management	1. Identity Spoofing	8. Confused Deputy (OAuth Proxy)	16. Credential Theft/Token Theft 17. Replay Attacks/Session or Handle Hijacking 18. OAuth/Legacy Auth Weaknesses 19. Session, Token, or Handle Leakage	Agent Identity Secure Delegation (i.e. OAuth delegation)
MCP-T2	Missing or Improper Access Control		9. Insecure Human-in-the-Loop 10. Improper Multitenancy	8. Privilege Escalation 20. Excessive Permissions/Overexposure	Secure Delegation Access Control
MCP-T3	Input Validation/Sanitization Failures			21. Command Injection 22. File System Exposure/Path Traversal 23. Insufficient Integrity Checks	Data Sanitization Guardrails Sandboxing and Isolation Explicit tool parameters, resource URIs, or server configuration replacing deprecated Roots
MCP-T4	Data/Control Boundary Distinction Failure	2. Tool Poisoning 3. Full Schema Poisoning 4. Resource Content Poisoning	11. Prompt Injection	21. Command Injection	Input Sanitization, Guardrails Context Isolation
MCP-T5	Inadequate Data Protection and Confidentiality Controls			24. Data Exfiltration & Corruption 22. File System Exposure/Path Traversal	Sandboxing and Isolation Access Control Guardrails

Threat	Threat Category	MCP Specific	MCP Contextualized	Conventional Security	Control and Mitigation
MCP-T6	Missing Integrity/Verification Controls	4. Resource Content Poisoning 5. Typosquatting/Confusion Attacks 6. Shadow MCP Servers		25. Supply Chain Compromise and Privileged host-base Attacks	Cryptographic Integrity Remote Attestation MCP server integrity
MCP-T7	Session and Transport Security Failures		12. Man-in-the-Middle (MITM)	17. Replay Attacks/Session or Handle Hijacking 19. Session, Token, or Handle Leakage 26. Unrestricted Network Access 27. Protocol Security Gaps 28. Insecure Descriptor Handling 23. Insufficient Integrity Checks 29. CSRF Protection Missing 30. CORS/Origin Policy Bypass	Network and Transport Security
MCP-T8	Network Binding/Isolation Failures	6. Shadow MCP Servers	10. Improper Multitenancy	31. Malicious Command Execution 32. Dependency/Update Attack 26. Unrestricted Network Access	Network and Transport Security Sandboxing and Isolation

Threat	Threat Category	MCP Specific	MCP Contextualized	Conventional Security	Control and Mitigation
MCP-T9	Trust Boundary and Privilege Design Failures	7. Overreliance on the LLM	13. Consent/User Approval Fatigue		Secure tool design UX Design
MCP-T10	Resource Management/Rate Limiting Absence		14. Resource exhaustion and denial of wallet	33. Payload Limit/DoS	Network and Transport Security
MCP-T11	Supply Chain and Lifecycle Security Failures	6. Shadow MCP Servers		25. Supply Chain Compromise	Lifecycle Governance
MCP-T12	Insufficient Logging, Monitoring, and Auditability		15. Invisible Agent Activity	34. Lack of Observability	Logging Lifecycle Governance

3.1.1 MCP Specific

1. **Identity Spoofing** Weak or misconfigured authentication in MCP deployments could allow attackers to impersonate legitimate clients or the agents acting on their behalf, corrupting audit trails or gaining unauthorized access to server resources.
2. **Tool Poisoning** Malicious modification of tool metadata, configuration, or descriptors injected into clients via the tools/list method. This can cause AI agents or MCP components to invoke, trust, or execute compromised tools, potentially leading to data leaks or system compromise. As the MCP specification notes, 'descriptions of tool behavior such as annotations should be considered untrusted, unless obtained from a trusted server' (Key Principles), making tool poisoning a recognized risk when clients connect to unvetted servers.
3. **Full Schema Poisoning (FSP)** Attackers compromise entire tool schema definitions at the structural level, injecting hidden parameters, altered return types, or malicious default values that affect all subsequent tool invocations while maintaining apparent compatibility and evading detection by appearing legitimate to monitoring systems. Unlike Tool Poisoning (#2): Goes beyond poisoning individual tool metadata to compromise the entire structural definition and type system of tools.
4. **Resource Content Poisoning** Attackers embed hidden malicious instructions within data sources (databases, documents, API responses) that MCP servers retrieve and provide to LLMs, causing the poisoned content to execute as commands when processed, effectively achieving persistent prompt injection through trusted data channels rather than direct user input. Unlike Prompt Injection (#11): Malicious instructions are embedded in backend data sources, not user-provided prompts. Unlike Tool Poisoning (#2): Poisons the actual data/content retrieved by tools, not the tool definitions themselves. This attack surface may be expanded with transitive or composed MCP server calls.
5. **Typosquatting/Confusion Attacks** Malicious actors create MCP servers or tools with names/descriptions similar to legitimate ones, tricking clients or AI agents into invoking harmful tools due to naming confusion or LLM hallucination. The MCP specification provides guidance on making tool origins and inputs visible to users and recommends human-in-the-loop approval for tool invocations (User Interaction Model), but consent

fatigue—where users reflexively approve prompts without careful review—can significantly undermine these protections.

6. **Shadow MCP Servers** Unauthorized, unmonitored, or hidden MCP server instances create blind spots, increasing risk of undetected compromise and covert data exfiltration. These servers pose governance and compliance risks and may be malicious or easily compromised.

7. **Overreliance on the LLM** MCP server developers may implement overly permissive tools, assuming the LLM will invoke them correctly and safely. However, model-level controls (trained refusals, safety classifiers, etc.) are not ironclad—even capable models can be manipulated through prompt injection, make errors in judgment, or be replaced with weaker models that lack equivalent safeguards.

3.1.2 MCP Contextualized

8. **Privilege Escalation via Authentication and Authorization Bypass** Attackers exploit misconfigured roles, credentials, ACLs, trust relationships, or flawed delegation logic to gain elevated permissions and access unauthorized resources. In MCP deployments, this includes privilege escalation, as well as attacks that leverage the MCP server's intermediary role in multi-user token delegation. For example, confused deputy attacks can occur when an MCP server acting as an OAuth proxy fails to properly validate authorization context—allowing attackers to manipulate the server into using another user's credentials to perform privileged operations. See the official MCP guidance on preventing Confused Deputy attacks.
9. **Insecure Human-in-the-Loop** Missing or insufficient human-in-the-loop consent checks can allow an MCP server to take risky actions not authorized by the user.
10. **Improper Multitenancy** An attacker may exploit weak isolation between tenants or users, such as shared memory between processes, shared secrets and credentials, or shared state that outlives a single request (explicit state handles, task state, continuation state, and cached tool or resource results), to access or manipulate unauthorized data.
11. **Prompt Injection** LLMs have insufficient boundaries between input data and instructions. Attackers craft malicious inputs to manipulate LLMs or MCP components to perform unintended or harmful actions such as data exfiltration, privilege escalation, or unauthorized command execution. These malicious instructions can be sent *directly* to the LLM (e.g., through a server's direct LLM provider integration or through legacy Sampling flows) or *indirectly* by embedding instructions in prompts, resources, tool metadata, tool outputs, or MCP App UI content. This threat exists whenever untrusted input can reach the LLM's context window.
12. **Man-in-the-Middle (MITM)** Exploiting insecure network transport (lack of TLS, improper certificate validation, or missing mutual authentication) to intercept, modify, or reroute data between MCP components, enabling data theft or manipulation.
13. **Consent/User Approval Fatigue** Flooding users with excessive consent or permission prompts, causing habituation and leading to blind approval of potentially dangerous or malicious actions.
14. **Resource exhaustion and denial of wallet** Attackers trigger an excessive number of LLM, tool, or other API calls leading to unexpected costs or resource exhaustion and denial of service.
15. **Invisible Agent Activity** Agents or servers operate covertly, mimicking valid workflows but executing malicious or unauthorized actions without detection.

Conventional security threats to MCP, and definitions of the twelve threat categories, are discussed in the Appendix.

3.2 Controls and Mitigations

3.2.1 Agent Identity

All requests should be traceable across the entire execution chain: the end user or initiating agent, any intermediate MCP servers, and the tools or services that performed the resulting actions. Standards are emerging to define the identity of agents and servers. One of these is SPIFFE / SPIRE, which provides cryptographic workload identities that can be granted authorization to resources. The SPIFFE ID can be used in token exchange as the subject or actor depending on the flow.

Secure identity, authentication, and authorization across the agentic and MCP ecosystem is an extremely active area of research and development. We will provide a much deeper analysis of the problem space in a subsequent white paper.

3.2.2 Secure Delegation and Access Control

To mitigate against privilege escalation, MCP servers should operate with the minimum privileges necessary. OAuth provides a widely adopted framework for secure delegation, with extensions that support fine-grained scope control and secure token flows (see MCP Authorization).

- Leverage existing identity providers to provide user authentication using standards such as OIDC
- Register MCP clients with the IAM provider. Prefer Client ID Metadata Documents where supported; use Dynamic Client Registration only as a compatibility fallback for authorization servers that do not support Client ID Metadata Documents
- Bind client credentials, access tokens, and cached registration state to the authorization server issuer that issued them; do not reuse credentials when protected resource metadata points to a different authorization server
- Validate the OAuth authorization response iss parameter when present, and reject missing iss responses when the authorization server advertises RFC 9207 support
- Declare the correct OIDC application_type during Dynamic Client Registration so native, CLI, desktop, and localhost applications are not accidentally treated as web applications
- Do not passthrough the OAuth tokens provided by the user
- Perform token exchange with the authorization server to provide full accountability (RFC8693)
- Reduce scopes for least privilege, such as removing write scopes when only read access is required, and use runtime scope challenges for step-up rather than requesting maximal scopes up front
- Use short-lived tokens and support proof-of-possession (DPoP) to prevent replay attacks (RFC9449)
- Protect refresh tokens as confidential credentials, request them only when needed, and preserve previously granted scopes during step-up authorization so users do not lose required permissions during incremental consent
- Fine grained authorizations, through Rich Authorization Requests (RFC9396), limit requests to specific resources or tool parameters

All endpoint services should implement robust access control models, such as role-based access control (RBAC) or attribute-based access control and evaluate against claims made by the identity provider, such as role membership, job title, or work location. Additionally, robust policy languages including Open Policy Agent (OPA), Cedar, or OpenFGA provide robust, flexible, and secure protections.

3.2.3 Input and Data Sanitization and Filtering

A secure implementation of MCP requires strong data sanitization, input validation, and guardrails to protect against malicious or unsafe data inputs. Existing best practices for securing other RPC protocols should be applied.

All inputs should be strictly validated using allowlists at every trust boundary, with particular attention to sanitizing file paths through canonicalization, employing parameterized queries for database operations, and applying context-aware output encoding appropriate to each execution context (SQL, shell, HTML). Tool developers can include cryptographic checks, such as message authentication codes, digital signatures and encryption to ensure the end-to-end integrity and confidentiality of tools and resources.

LLM guardrails should treat all AI-generated content as untrusted input requiring the same rigorous validation as direct user input, deploying prompt injection detection systems that analyze patterns and structured formats (strict JSON schemas) to maintain clear boundaries between instructions and data. This includes all data returned from MCP servers including tool and resource definitions, resources, prompts, elicitation requests, MCP App UI resources, task state, and tool responses. Tool schemas in the 2026-07-28 release support full JSON Schema 2020-12 features, including composition, conditionals, and $ref; implementations should bound validation depth and runtime, avoid automatic dereferencing of external references, and treat x-mcp-header schema annotations as security-sensitive because they influence HTTP headers visible to intermediaries.

3.2.4 Cryptographic Integrity and Remote Attestation

Hardware Trusted Execution Environments (TEE) like Intel TDX, and AMD-SEV/SNP provide stronger isolation and can provide protection against runtime tampering of trusted servers, such as tool poisoning due to server compromise. Combined with remote attestation, TEEs can isolate MCP servers and clients from compromised hardware, malicious administrators of server infrastructure, and certain classes of co-tenancy threats. For containerized deployments, consider the use of confidential containers (CoCo) that run containers in TEEs, and use remote attestation to verify the trustworthiness of the TEEs and what is running in them.

Threat Category	How TEE + Remote Attestation provide Mitigation
MCP T5: Inadequate Data Protection and Confidentiality Controls	MCP Client and MCP Servers are isolated from other software running on the hardware, and also from the operator of the hardware, by running them in TEEs. Insider and privileged access to the TEEs is prevented there by minimizing the attack vectors for this threat. Good system design should include other controls for verifying the attestations, and delivery of secrets and sensitive data via secure channels to the MCP Clients and Servers running in attested TEEs. Compromised and/or Malicious co-tenant cannot access or tamper with Client and MCP Server code or data that is running inside TEEs. Additional controls would be necessary to ensure the data is protected in-transit and at-rest with tenant-specific keys, and RA-TLS, etc. With end to end data protection designs built on TEEs, Identity credentials, access tokens, keys and secrets can be protected from compromise and exposure. Compromised or Incorrect (or shadow) MCP Server launched in TEEs have different sets of measurements, and these will fail to attest, and MCP Client can refuse to interact with the MCP Servers. Credentials and access tokens will not be provided to the MCP Servers. TEEs however cannot mitigate against vulnerabilities in the running code, and should be complemented with runtime controls. (Seccomp, Apparmor, etc.)
MCP T9: Trust Boundary and Privilege Design Failures	Privileged software host-based attacks will not affect the MCP Client and the MCP Servers when they are running in TEEs. The host system, host OS, host firmware and the host Hypervisor are outside the Trust Boundary of the TEEs. However, sophisticated host-based attacks that include certain physical attacks on the hardware are not mitigated by TEEs.

Complement the use of TEEs with other sandboxing and isolation technologies.

3.2.5 Sandboxing and Isolation

Agents and MCP servers should be executed with least privilege. MCP servers that interact with the host environment (e.g. by accessing files, running commands, issuing network connections), or that execute LLM-generated code, should always run in a sandbox to mitigate against potential

safety and security threats.

LLM-generated code and commands may contain hallucinations, bugs, or vulnerabilities, and should not run with full user privileges. MCP servers are commonly deployed in containers for ease of use, but containers should not be relied upon as a strong security boundary. Consider additional sandboxing (gVisor, Kata Containers, SELinux sandboxes) for stronger isolation.

3.2.6 Cryptographic Verification of Resources

Organizations developing MCP servers must provide cryptographic signatures and software bill of materials (SBOMs) for all server code to verify provenance. Organizations deploying MCP clients and servers should obtain and verify the contents and cryptographic signatures prior to deployment, and have policies restricting the approved sources and signing keys. TLS should be used to protect all data in transit. Remote attestation can further verify that servers are running expected code in a trusted environment. When supported, end-to-end cryptographic signatures can prove the authenticity of resources returned by MCP servers.

3.2.7 Transport Layer Security

MCP is structured around distinct communication layers that facilitate robust interaction between systems. At the transport layer, MCP leverages two primary communication methods:

- **stdio Transport:** A direct, pipe-based stream communication channel, typically used for intra-process or tightly integrated inter-process communications. JSON-RPC messages flow directly via standard input/output streams. This transport is most commonly used for local servers.
- **Streamable HTTP Transport:** A generalized HTTP-based transport channel supporting JSON-RPC over independent POST requests. Each request may receive a normal JSON response or a response stream for request-scoped progress, cancellation, and notification events. This transport is most commonly used for remote servers.

At the higher-level protocol layer, MCP employs JSON-RPC 2.0 to standardize the formatting and processing of commands and responses communicated across these transport channels. JSON-RPC ensures structured messaging, enabling interoperability and clarity of communication across diverse platforms.

However, these transport and protocol layers, when improperly secured or configured, can expose MCP clients and servers to multiple vulnerabilities. The following table summarizes critical missing security controls across MCP's layers and transports, along with specific exploits enabled by each gap:

Required Security Control	Protocol	Example Exploits
Payload Limits	All Transports	Large payload and recursive payload DoS
Client-Server Authentication/Authorization	HTTP-based Transports	Impersonation, unauthorized RPC calls, token replay
Downstream Authentication/Authorization	All Transports	Impersonation, confused deputy flows, unauthorized upstream API calls
Mutual TLS Authentication	HTTP-based Transports	Impersonation attacks
TLS Encryption	HTTP-based Transports	Stream tampering, TLS downgrade
Cross-Origin (CORS)	HTTP-based Transports	Cross-origin data leaks
CSRF Protection	HTTP-based Transports	Forged POST requests

Required Security Control	Protocol	Example Exploits
Protocol Version and Request Metadata Validation	Streamable HTTP	Downgrade attacks, header/body confusion, incorrect routing
Mcp-Method / Mcp-Name Header Validation	Streamable HTTP	Gateway bypass, rate-limit evasion, executing a different operation than the intermediary inspected
Cache Scope Enforcement	Streamable HTTP	Cross-user cache leakage, stale tool or resource definitions, tenant data exposure
Secure Descriptor Handling	stdio Transport	Hijacking via inherited descriptors
Integrity Checks	All Transports	Replay, spoofing, poisoned responses

Implementing the above controls across transport and protocol layers significantly reduces the attack surface of MCP deployments. For implementations targeting the 2026-07-28 release, gateways and servers should validate that MCP-Protocol-Version, Mcp-Method, and Mcp-Name agree with the JSON-RPC body before routing, authorization, rate limiting, or logging decisions are made. The new request headers improve operability because intermediaries no longer need to parse the full body to route tools/call, resources/read, and prompts/get, but they also create a split-brain risk if the intermediary trusts headers and the server trusts the body. Header mismatch must be treated as a security-relevant failure.

Protocol-level sessions and the Mcp-Session-Id header are removed in the 2026-07-28 release. This simplifies horizontal scaling because remote servers no longer need sticky sessions or shared protocol session stores, but it moves state management into application-visible references and _meta. Server-held references such as task IDs and continuation handles must be unguessable, opaque, scoped, tenant-bound, logged, expiring, and revocable. Client-held sealed state such as requestState is a different case: the server retains no copy to revoke, so it must be integrity-protected and rejected when verification fails. In both cases a client must not be able to read meaning out of the value, nor alter it and have the server honor the result. Named references such as resource URIs stay predictable and readable by design, and must be authorized on every read instead. None of these may become a bearer token that bypasses normal authorization checks. Section 3.2.12 defines the three classes and the properties each requires.

_meta now carries protocol version, client identity, and client capabilities on every request. Identity and capability claims arriving in _meta are untrusted input, because they record what a caller asserts about itself and carry no proof of it. Servers must reconcile them against the principal authenticated by the access token, mutual TLS peer certificate, or workload identity, and must treat a mismatch as a security-relevant failure rather than resolving it in favor of the claim.

Caching is now explicit for cacheable results through ttlMs and cacheScope. Clients and intermediaries should honor private scope for user- or tenant-specific results, avoid caching sensitive resource reads unless policy permits it, and invalidate pinned tool metadata when cache lifetimes expire or list-change notifications arrive. Long ttlMs values improve availability and cost, but they increase exposure to stale policy, stale schemas, and delayed revocation after a server or tool compromise.

For deployments handling long-lived sensitive data (biometrics, identity roots, classified material), classical asymmetric key exchange is vulnerable to “Harvest Now, Decrypt Later” (HNDL) attacks

from future quantum adversaries. Organizations in this situation should plan migration to hybrid post-quantum TLS — combining classical X25519 with NIST FIPS 203 ML-KEM-768 — to protect data whose sensitivity extends beyond the quantum computing horizon. See the companion addendum, *Quantum-Resistant AI Infrastructure: Implementing Post-Quantum Cryptography in MCP Architectures*, for a detailed implementation roadmap.

3.2.8 Secure Tool and UX Design

Tool and UX design represent a critical security control point in Model Context Protocol (MCP) deployments. While much attention is paid to model safety and prompt injection defenses, the tools that agents invoke are often the actual execution surface where security boundaries are crossed and sensitive operations are performed. Poor tool design can undermine even the most robust authentication and authorization controls by creating overly permissive capabilities or delegating security-critical decisions to the LLM itself.

Each tool should have a single, clearly defined purpose with explicit boundaries on what it can and cannot do. When possible, create use-case driven or purpose-built tools, avoiding excessively powerful tools, e.g., execute a prepared statement versus executing any SQL statement. Tool implementations should not rely on the LLM to perform security-critical operations, validate inputs, or enforce constraints.

Safe and secure execution should not rely solely on the human user, who may not understand the security implications of frequent security prompts and can easily become fatigued. Security-relevant messages and elicitations should be clear, indicating the implications of the request, and unambiguous what is being requested.

3.2.9 Human-in-the-loop

There is the possibility that a large language model, legit or poisoned, decides to execute a tool in a dangerous way. MCP hosts and clients, in general, allow users to disable the confirmation prompt. There are two approaches organizations considering this risk unacceptable may implement to reduce its probability and impact:

- enforce the use of MCP hosts and clients with a configuration that unprivileged users cannot change and that keeps the confirmation prompt enabled.
- use elicitation on the MCP server side to request the user confirmation of actions.

In the 2026-07-28 release, server-to-client requests such as elicitation are no longer an open-ended bidirectional channel. They are request-scoped: a server may ask for additional input only while processing a client-initiated request, and the Multi Round-Trip Requests pattern returns an InputRequiredResult containing inputRequests and requestState. This is a useful security tightening because every prompt can be traced to a user- or agent-initiated action. Implementations should preserve that causality in audit logs, validate returned inputResponses against the original request and policy decision, and avoid presenting server-supplied text as trusted UI copy. The requestState is server-sealed state carried by the client, not a reference the server can look up. Servers must treat a returned value as attacker-controlled, verify its integrity before acting on it, and bind it to the authenticated principal and the originating request.

3.2.10 Logging

Implement at all layers (MCP host, client and server) the capability to store a log of what tools have been decided to use, with which parameters, and as a result of which prompt. Having a log of the decisions made is crucial in order to troubleshoot or perform forensics in case of a security event.

Leverage the use of centralization tools like MCP gateways or proxies, for example, between the MCP clients and the MCP servers, to centralize there key functionality (e.g. logging) and avoid the need to implement it on each component.

The MCP Logging feature is deprecated in the 2026-07-28 release; new implementations should not depend on protocol-level logging methods for security telemetry. For stdio transports, diagnostic logs should use stderr; for structured observability, use OpenTelemetry and propagate W3C Trace Context in _meta using the specified traceparent, tracestate, and baggage keys. Logs should capture request headers (MCP−Protocol−Version, Mcp−Method, Mcp−Name), request IDs, task IDs, explicit state handles, authorization issuer/audience/scope decisions, cache decisions, and extension identifiers while redacting tool arguments and results according to data classification.

3.2.11 Lifecycle and Governance

Organizations must:

- implement mandatory code signing verification for all MCP servers before installation,
- use private package repositories with security scanning and approval workflows,
- deploy software composition analysis (SCA) tools to detect vulnerable dependencies,
- implement allow-lists of approved MCP servers with documented security reviews,
- At Level 4, run MCP servers and clients in TEEs or confidential containers and use remote attestation prior to interactions where the threat model, regulation, or platform supports it (see §3.3.2 Isolation and Sandboxing),
- use cryptographic hash verification for package integrity,
- and deploy binary authorization that prevents execution of unsigned or unverified code.

Supply chain security requires:

- implementing software bill of materials (SBOM) tracking for all MCP components,
- using dependency pinning with hash-based verification rather than version ranges,
- deploying automated vulnerability scanning for MCP servers and dependencies,
- implementing secure software development lifecycle (SSDLC) practices for internal MCP servers,
- using reproducible builds to verify package authenticity,
- and monitoring security advisories and CVE databases for known vulnerabilities in dependencies.

Lifecycle management demands:

- maintaining centralized inventory of all deployed MCP servers with metadata (version, owner, purpose),
- implementing automated discovery to detect shadow or unauthorized MCP deployments,
- deploying lifecycle policies that automatically deprecate or remove outdated servers,
- using configuration management tools (Ansible, Puppet, Chef) to maintain consistent deployments,
- implementing rollback capabilities for problematic updates,
- and deploying update management processes with testing and staged rollout.

Operational practices include:

- regular security reviews and re-certification of approved MCP servers,
- automated scanning for shadow deployments across the organization,
- decommissioning procedures that ensure complete removal of deprecated servers,
- and version tracking with forced upgrade policies for servers with known vulnerabilities.

The formal Extensions Framework in the 2026-07-28 release adds another lifecycle dimension. Extensions use reverse-DNS identifiers, are versioned independently from the core specification, may live in separate ext−∗ repositories with delegated maintainers, and progress through an Extensions Track in the SEP process. Organizations should manage extensions like protocol-level dependencies: require ownership, version pinning, security review, compatibility testing, and ex-

plicit approval before an MCP client or server advertises support.

And, lastly, proper observability should be implemented across the stack to provide sufficient visibility to ensure compliance and enable developer debugging and incident investigation. Immutable records of actions and authorizations, such as token exchange implemented by an IDP (identity provider), provides accountability pertaining to who requested an action and how it was authorized. All interactions with the agent, tools, prompts, and models should be logged. OpenTelemetry provides end-to-end linkability of actions and is being widely adopted and integrated into many agentic tools and MCP servers and provides a consistent set of APIs and schemas.

3.2.12 MCP Protocol Version Transition

The 2026-07-28 release changes enough protocol assumptions that organizations should treat migration as a security review, not only a compatibility update. The most important impacts are:

- **Stateless core:** Remove dependencies on `initialize`, `notifications/initialized`, and `Mcp-Session-Id` for new implementations. Use `server/discover` for server capabilities and put protocol version, client identity, and client capabilities in per-request `_meta`.
- **Explicit state:** Replace hidden protocol session state with explicit references passed as ordinary parameters. Capability-bearing references are the ones a holder can use to reach state, and they divide by where that state lives. Named references carry no capability at all. Conflating the three applies the wrong control:
  - *Server-held references*, such as task IDs and continuation handles, name state the server retains. The server mints them and they carry no meaning to the client. Since the removal of `tasks/list` leaves possession of the reference as the discovery mechanism, they must be unguessable, scoped to user, tenant, tool, and lifetime, expiring, revocable, and logged. The server revokes one by discarding the state it names.
  - *Client-held sealed state*, such as the `requestState` of an `InputRequiredResult`, is the state itself, sealed by the server and carried by the client. Unguessability is not the control here, because the value is a sealed payload rather than a lookup key. It must be opaque to the client, integrity-protected with an HMAC or AEAD, and rejected when verification fails. The authenticated principal, an expiry, and an identifier for the originating request belong inside the seal. The server retains nothing, so revocation is not available and a short expiry becomes the only bound on exposure.
  - *Named references* are resource URIs and tool parameters. They are stable, semantic, and expected to be predictable, so unguessability does not apply to them and is not the right control. They require authorization on every read, because a caller who can name a resource has not thereby shown any entitlement to it.

  The Tasks extension permits a server to treat a task ID as a bearer token for its stored state, and for that reason requires enough entropy that a third party cannot enumerate or guess one. This paper takes the stricter position: possession should not be sufficient by itself, and authorization should still be evaluated on every request that presents a reference, against the authenticated principal rather than against the reference itself.
- **Migration and mixed-version operation:** During the transition, a server that accepts both the legacy session model and the stateless model runs two authorization paths, and the legacy path established authorization once at `initialize` rather than per request. Servers supporting both must enforce per-request authorization on the legacy path as well. A dual-era server selects its behavior from how the client opens, so the era in use is effectively a client choice, and the protocol supplies no floor of its own. Servers should therefore set a minimum supported version as policy and decline anything below it, which the specification already accommodates: a server returns `UnsupportedProtocolVersionError` both for versions it does not know and for known versions it has chosen not to support. Legacy `Mcp-Session-Id` support should be inventoried and carry a documented sunset date.
- **Server-to-client interactions:** Treat `InputRequiredResult` and task `input_required` states as

part of the original request workflow. Do not design systems that allow unsolicited server prompts outside a client-initiated request.

- **Extensions:** Track official and third-party extensions by reverse-DNS identifier, version, maintainer, and approval status. Capability negotiation is now a security boundary because extensions can add UI surfaces, task lifecycles, authorization flows, and transport-visible behavior.
- **MCP Apps:** Treat server-rendered HTML UI as untrusted content even when delivered by an approved server. Hosts should enforce sandboxed iframes, capability allowlists, CSP, origin isolation, postMessage validation, UI resource integrity review, and audit of every UI-initiated JSON-RPC action through the normal MCP consent and policy layer.
- **Tasks:** The Tasks extension replaces the 2025-11-25 experimental core API. Servers may return a task handle from tools/call; clients drive lifecycle through tasks/get, tasks/update, and tasks/cancel. tasks/list is removed, so task discovery and authorization must be scoped through known handles rather than broad enumeration. Task handles require the same tenant scoping, TTL, cancellation, and audit controls as other durable execution references.
- **Deprecations:** Roots, Sampling, and Logging remain available during the deprecation window but should not be adopted by new systems. Prefer tool parameters, resource URIs, or server configuration instead of Roots; direct LLM provider integration instead of Sampling; and stderr or OpenTelemetry instead of protocol Logging.
- **Schema and errors:** Tool schemas now use JSON Schema 2020-12 by default and can express richer validation logic. Implementations must be robust against expensive schemas, schema poisoning, and unsafe external references. Resource-not-found handling should be updated from the older MCP custom −32002 code to JSON-RPC −32602 (Invalid Params).

3.3 Security Assurance Profiles

The preceding sections define twelve threat categories and their controls and mitigations. A flat list of controls, however, does not help practitioners determine which controls apply to their specific deployment. A sandbox experiment and a multi-tenant production system do not share the same threat surface. Applying uniform requirements causes friction: sandbox experiments stall under heavy compliance burdens, while production systems carry hidden risk due to underinvestment.

Assurance profiles map specific security controls to specific deployment contexts. This section defines four assurance levels for MCP deployments. Each level specifies concrete control requirements across eight security dimensions, maps back to the MCP-T1 through MCP-T12 threat categories defined above (with cross-references to the OWASP MCP Top 10), and aligns with the deployment patterns in Appendix 6.1. The 2026 MCP roadmap identifies enterprise readiness as a top priority; these profiles provide the security dimension of that effort.

The level numbering follows conventions used in frameworks like SLSA: higher numbers indicate stronger assurance, and levels are cumulative (Level 3 includes everything in Level 2). Unlike NIST SP 800-63, which separates assurance across identity proofing (IAL), authentication (AAL), and federation (FAL), these profiles combine multiple security dimensions into a single deployment-oriented tier for operational simplicity.

3.3.1 Level Definitions

Level	Alias	Intended Use	Trust Assumptions
Level 1	Sandbox	Local development, single-user experiments, proof-of-concept work	Single user, no sensitive data, failures are recoverable. No access to production credentials or live data.
Level 2	Internal	Internal enterprise deployments, team-shared environments, staging	Authenticated users within an organization. Moderate blast radius. Incidents must be diagnosable after the fact.
Level 3	Production	Production workloads handling sensitive or business-critical data	Active threat surface. Data loss or unauthorized access has material business impact. Full auditability required.
Level 4	Regulated	Multi-tenant platforms, adversarial environments, regulatory scope	Active adversaries assumed. Regulatory audit obligations. Strong tenant isolation and workload attestation required.

3.3.2 Control Requirements by Level

Identity and Authentication

Control	L1	L2	L3	L4
MCP client-server authentication	Implicit (local process via stdio)	MUST: OAuth 2.1 with PKCE for all remote server connections	MUST: OAuth 2.1 with PKCE, short-lived credentials, and Client ID Metadata Documents where supported	MUST: OAuth 2.1 with PKCE, short-lived credentials, and enterprise-managed authorization where applicable
Authorization issuer validation	Not required	MUST: validate issuer metadata during authorization server discovery	MUST: validate RFC 9207 iss in authorization responses and bind registration state to the issuing authorization server	MUST: issuer binding enforced centrally with policy alerts on issuer migration or mismatched protected resource metadata

Control	L1	L2	L3	L4
Agent identity	Not required	SHOULD: agents registered in a local inventory with unique identifiers	MUST: standardized workload identity (e.g., SPIFFE / SPIRE SVIDs) tied to specific code versions	MUST: workload identity with cryptographic attestation verifying the execution environment matches the declared manifest
User identity propagation	Not applicable	If acting on behalf of a user, SHOULD: preserve subject identity to downstream authorization components	MUST: token exchange carrying distinct actor (the agent) and subject (the human or initiating system) claims. For system-initiated workflows, a distinct workload identity may be used instead.	MUST: token exchange with delegation chain preserved for audit. Prior delegation hops should be retained for forensics, but authorization decisions must be based on the token's current actor and subject claims.
Credential storage	Local config acceptable. Real credentials discouraged; if production or user credentials are present, reclassify as Level 2.	MUST: OS keychain or secrets manager	MUST: secrets manager with automated rotation policy	MUST: long-lived private keys for signing and identity should be protected by hardware-backed or isolated keystores where available. Ephemeral access tokens must remain short-lived and runtime-confined.

Credential lifetime	Real credentials discouraged. If used, treat as Level 2.	SHOULD: bounded lifetime, rotation on schedule	MUST: short-lived tokens (minutes to hours); refresh tokens rotated and stored as confidential credentials	MUST: short-lived sender-constrained credentials, typically minutes, bounded by transaction or task risk

Threat coverage: MCP-T1 (Identity/Auth Failures), MCP-T2 (Authorization Errors) **OWASP MCP mapping:** MCP01 (Token Mismanagement), MCP07 (Insufficient Auth)

Authorization and Delegation

Control	L1	L2	L3	L4
Tool-level authorization	Not required	SHOULD: tool allowlists per agent role	MUST: attribute-based access control (ABAC) / policy-based access control (PBAC) for tool access, supplemented by tool-based access control (TBAC) enforcing parameter-level constraints. TBAC evaluates the specific tool request against verifiable agent identity before execution.	MUST: TBAC with continuous real-time evaluation, anomaly detection, and automated revocation of compromised agent credentials

Control	L1	L2	L3	L4
Scope management	No restriction	SHOULD: scoped permissions per server connection	MUST: least-privilege scopes; incremental scope consent via WWW-Authenticate challenges rather than requesting maximal scopes upfront; clients preserve previously granted scopes during step-up	MUST: structured authorization intent via Rich Authorization Requests (RFC 9396) using the authorization_details parameter for all sensitive tool operations
Delegation depth	Not applicable	SHOULD: defined maximum depth for agent chains	MUST: enforced depth limits with TTL constraints and audience restrictions	MUST: enforced depth limits, audience restrictions, and sender-constrained tokens at every hop
Token binding	Not required	Not required	MUST: sender-constrained tokens (DPoP or mTLS) for all delegated operations involving sensitive data	MUST: sender-constrained tokens with hardware-attested key material where platform supports it
Scope narrowing on delegation	Not applicable	SHOULD: scope narrows at each hop	MUST: scope narrows at each hop, cannot exceed delegating principal's effective permissions	MUST: scope narrows at each hop with cryptographic binding to transaction path

Control	L1	L2	L3	L4
Audience restriction	Not required	SHOULD: audience (aud) claim validation on received tokens	MUST: Resource Indicators (RFC 8707) specifying the target MCP server's canonical URI. Authorization server must reject tokens where audience does not match.	MUST: Resource Indicators enforced globally, integrated with dynamic endpoint discovery via Protected Resource Metadata (RFC 9728)
Token passthrough	Not applicable	MUST: MCP servers must not accept tokens intended for themselves and forward those same tokens to upstream APIs. See MCP security best practices.	MUST: downstream authentication managed exclusively via token exchange (RFC 8693) producing distinct, scoped tokens for each upstream resource	MUST: token exchange with sender-constrained bindings for all downstream calls
Human-in-the-loop	Warning on untrusted tools	MUST: explicit user confirmation for all destructive or state-mutating actions. MCP elicitation and InputRequiredResult provide request-scoped mechanisms for server-requested user input.	MUST: configurable centralized approval policies with step-up authentication for high-impact actions; approval prompts traceable to the initiating request	MUST: multi-party approval workflows for irreversible or high-value operations, with continuous context validation

Threat coverage: MCP-T2 (Authorization Errors), MCP-T9 (Trust Boundary Failures) **OWASP MCP mapping:** MCP02 (Privilege Escalation), MCP07 (Insufficient Auth)

Transport and Network Security

Control	L1	L2	L3	L4
Transport encryption	Not required for stdio. Localhost HTTP acceptable.	MUST: TLS for all remote connections	MUST: TLS 1.3 and mTLS for server-to-server connections, certificate validation enforced	MUST: mTLS governed by workload identity federation (e.g., SPIFFE / SPIRE) and hardware trust anchors
Network binding	MUST for HTTP transport: bind exclusively to 127.0.0.1; binding to 0.0.0.0 is prohibited. stdio transport preferred. See MCP transport security warning.	MUST: explicit internal interface binding mapped to authenticated ingress. No 0.0.0.0.	MUST: network segmentation between MCP components	MUST: dedicated network segments, default-deny egress with explicit allowlists, proxy enforcement, and logging for outbound destinations
Origin and CSRF protection	MUST for HTTP transport: validate Origin header, validate Host header. Not applicable for stdio.	MUST: Origin validation, Host validation, and CSRF protections for all HTTP endpoints	MUST: strict origin policies with authentication required for all remote access	MUST: strict origin policies, additional request signing, and DNS pinning
Protocol request metadata	Optional for local stdio	MUST for Streamable HTTP: validate MCP-Protocol-Version, Mcp-Method, and Mcp-Name when required	MUST: reject header/body mismatches before authorization, routing, caching, or tool execution	MUST: gateway-level enforcement with alerts on HeaderMismatch and unsupported protocol versions
Payload limits	Optional	MUST: defined payload size limits and basic recursion depth controls	MUST: enforced payload and recursion depth limits with per-client, per-principal, and per-tenant rate limiting	MUST: enforced limits with anomaly-based throttling and tenant-aware cost controls
Message integrity	Not required	SHOULD: payload hashing and strict content-length validation	MUST: application-layer digital signatures (e.g., ECDSA P-256) over the full JSON-RPC message body	MUST: digital signatures with unique nonces and time-window validation to prevent replay

Control	L1	L2	L3	L4
Local HTTP exposure	If using HTTP, MUST: validate Origin, bind to localhost only. stdio or Unix domain sockets preferred. Unauthenticated local HTTP is non-compliant above Level 1.	N/A (remote connections require authentication)	N/A	N/A

Threat coverage: MCP-T7 (Session/Transport Failures), MCP-T8 (Network Binding Failures), MCP-T10 (Resource Management) **OWASP MCP mapping:** MCP05 (Command Injection), MCP09 (Shadow Servers)

Isolation and Sandboxing

Control	L1	L2	L3	L4
Execution isolation	SHOULD: execute within a restricted local user context. MUST NOT access production credentials or live data.	MUST: application sandboxing or containerized execution with resource limits	MUST: strong container isolation (e.g., gVisor, Kata Containers). No shared runtime across trust boundaries.	MUST: strong tenant isolation with attested workload identity. TEE / confidential containers should be used where threat model, regulation, or platform supports it.
Data isolation	Synthetic/mock data only. If production data is accessed, reclassify as Level 2+.	MUST: per-user data separation	MUST: per-tenant data isolation with encryption	MUST: per-tenant encryption with tenant-specific keys

Control	L1	L2	L3	L4
Context isolation	Not required	SHOULD: scope cached tool outputs and context to the current user and workflow	MUST: persistent context, memory, and cached tool outputs scoped to user, tenant, task, and agent boundary. Context from one workflow must not be reused in another without explicit policy authorization.	MUST: cross-tenant context sharing prohibited. Shared channels require redaction and release controls.
Snapshot and rollback	SHOULD: environment supports snapshot/rewind for experimentation	Optional	SHOULD: rollback capability for MCP server updates	MUST: rollback capability, staged rollouts, canary deployments

Threat coverage: MCP-T5 (Data Protection), MCP-T8 (Network Binding Failures), MCP-T9 (Trust Boundary Failures) **OWASP MCP mapping:** MCP10 (Context Over-Sharing)

Logging and Observability

Control	L1	L2	L3	L4
Action logging	Optional, primarily for debugging	MUST: structured logging capturing tool identity, caller identity, policy decision, resource target, outcome, request metadata, and correlation identifiers. Raw parameters and tool outputs must be logged only after redaction, hashing, or field-level tokenization.	MUST: comprehensive logging of tool invocations, authorization decisions, cache decisions, header mismatches, and security-relevant failures with full parameter redaction	MUST: immutable, tamper-evident logging of all interactions

Control	L1	L2	L3	L4
Delegation chain logging	Not required	SHOULD: correlation IDs linking related events	MUST: full delegation chain reconstruction via correlation IDs, with scope, binding type, and audience at each hop	MUST: full delegation chain reconstruction with policy version, attestation state, and scope at each hop
Distributed tracing	Not required	SHOULD: propagate correlation IDs across MCP host, client, and server	MUST: propagate W3C Trace Context in _meta (traceparent, tracestate, baggage) across MCP and downstream calls. Propagated baggage MUST be allowlisted by key and size-bounded, MUST NOT carry tenant or user data across a trust boundary, and server-supplied trace context MUST NOT overwrite the trace identity established by the client.	MUST: trace context correlated with identity, policy, runtime, and infrastructure telemetry
Log schema	Freeform	SHOULD: structured format, mapped to OCSF or CEF	MUST: structured format mapped to OCSF or CEF with agentic extension fields (delegation_path, attestation_state, correlation_id, mcp_method, mcp_name)	MUST: structured format with mandatory agentic fields, correlated in SIEM with model, runtime, and infrastructure telemetry

Control	L1	L2	L3	L4
Monitoring and alerting	Not required	SHOULD: centralized log aggregation	MUST: SIEM integration, anomaly detection on agent behavior	MUST: continuous monitoring, automated containment triggers, incident response hooks (kill-switch, tool disablement)

Threat coverage: MCP-T12 (Logging Gaps) **OWASP MCP mapping:** MCP08 (Lack of Audit and Telemetry)

Supply Chain and Lifecycle

Control	L1	L2	L3	L4
Server provenance	Warning when running unverified servers	SHOULD: provenance checks for tool definitions and server packages	MUST: code signing verification before installation, SBOM tracking	MUST: code signing, SBOM, reproducible builds, binary authorization. Execution should be blocked for any server lacking a signed SBOM verified within a defined window.
Server inventory	Not required	SHOULD: documented inventory of deployed servers with owner and trust status. The Official MCP Registry provides a discovery mechanism for known servers.	MUST: centralized inventory with metadata (version, owner, purpose, allowed deployment environments)	MUST: centralized inventory with automated discovery of shadow deployments. Production environments must detect and alert on unregistered MCP servers.
Extension inventory	Not required	SHOULD: approved extension list by reverse-DNS identifier and version	MUST: extension identifiers, versions, maintainers, and negotiated capabilities tracked in inventory and logs	MUST: policy enforcement for official, delegated, and experimental extensions, with block-by-default for unapproved extensions

Control	L1	L2	L3	L4
Update management	No restriction	SHOULD: version tracking	MUST: dependency pinning with hash verification, vulnerability scanning	MUST: dependency pinning, automated scanning, staged rollout, forced upgrades for known CVEs
Decommissioning	Not required	SHOULD: documented removal process	MUST: complete removal of deprecated servers, credential revocation	MUST: automated lifecycle policies, downstream delegation revocation on decommission

Threat coverage: MCP-T6 (Integrity/Verification), MCP-T11 (Supply Chain Failures) **OWASP MCP mapping:** MCP03 (Tool Poisoning), MCP04 (Supply Chain Attacks), MCP09 (Shadow Servers)

Tool Definition, Input, and Output Integrity

Tool descriptions, parameter schemas, and return values are attack surfaces, not ordinary metadata. The OWASP MCP Security Cheat Sheet and recent security research demonstrate that tool poisoning, schema corruption, and output-driven prompt injection are among the most effective attack vectors against MCP deployments. This dimension addresses MCP-T3 (Input Validation Failures) and MCP-T4 (Data/Control Boundary Failures).

Control	L1	L2	L3	L4
Tool schema integrity	SHOULD: review tool descriptions and parameter schemas before use	SHOULD: pin trusted tool definitions and alert on changes	MUST: cryptographically pin approved tool definitions; changes require review and re-approval	MUST: signed tool-definition manifests with change approval and rollback. Unsigned definitions rejected at runtime.
Schema validation	SHOULD: validate obvious dangerous inputs	MUST: validate against JSON Schema and reject undeclared parameters (additionalProperties: false) where tool semantics permit	MUST: support JSON Schema 2020-12 safely, including bounded composition, conditionals, and $ref; deny external reference dereferencing unless explicitly approved	MUST: signed schema manifests, bounded validation budgets, and policy review for schema constructs that widen accepted inputs

Control	L1	L2	L3	L4
Input validation	SHOULD: validate obvious dangerous inputs	MUST: sanitize file paths against directory traversal	MUST: enforce strict schemas, deny undeclared fields, validate file paths, URLs, command parameters, and x-mcp-header mirrored parameters. Reject symlinks and prevent path traversal.	MUST: policy-aware validation with per-tool allowlists, deny rules, and deep content inspection for encoded command syntax
Output handling	SHOULD: treat tool output as untrusted	MUST: sanitize tool outputs before returning them to the model context when reused downstream	MUST: classify and sanitize tool output to prevent downstream prompt injection, SSRF, and command injection. Strip control characters and apply context-aware encoding.	MUST: content classification and policy enforcement before output may influence another tool, server, or agent
Cacheable result handling	Not required	SHOULD: honor ttlMs and cacheScope, defaulting to private/no-store when uncertain	MUST: prevent cross-user and cross-tenant caching; revalidate pinned definitions after expiry or list-change notifications	MUST: centralized cache policy with security event invalidation and tenant-isolated cache keys
SSRF and traversal defense	Not required	MUST: restrict target URL schemes to HTTPS. Sanitize all file paths against directory traversal.	MUST: deny DNS resolution to loopback (127.0.0.0/8), link-local, and cloud metadata endpoints (169.254.169.254)	MUST: all network egress through strict allowlists managed by inspected egress proxies

Threat coverage: MCP-T3 (Input Validation Failures), MCP-T4 (Data/Control Boundary Failures)
OWASP MCP mapping: MCP03 (Tool Poisoning), MCP05 (Command Injection), MCP06 (Prompt Injection via Contextual Payloads)

State and Discovery Security

Control	L1	L2	L3	L4
Explicit state handle integrity	Not required	MUST: transport session identifiers must not be used as authenticators. Verify authorization on every request and scope explicit handles to the authenticated principal. Server-held references (task IDs, continuation handles) MUST be generated with a CSPRNG, MUST be unguessable and opaque to their holder, and MUST NOT expose tenant, user, or object identifiers to the client, consistent with the Tasks extension requirement that task IDs carry enough entropy to resist enumeration.	MUST: explicit handles, task IDs, and continuation state are tenant-bound, expiring, revocable, and logged. Stateful MCP servers must verify authorization per request. Revocation of the underlying grant, consent, or principal MUST invalidate outstanding handles, MUST initiate cancellation of in-flight tasks, and MUST NOT release task results to a revoked principal. Task cancellation is cooperative, so servers MUST NOT treat it as sufficient on its own. Servers MUST be able to enumerate live tasks per principal for revocation and incident response.	MUST: handle integrity with continuous re-evaluation and automated revocation on anomaly detection

Control	L1	L2	L3	L4
Request metadata trust	Not required	MUST: identity and capability claims carried in _meta are untrusted input and MUST NOT be used as an authorization input on their own, consistent with the specification's note that clientInfo and serverInfo are self-reported, unverified by the protocol, and not to be relied on for security decisions. Reconcile them against the principal authenticated by access token, mTLS peer certificate, or workload identity.	MUST: reject requests whose _meta identity claims conflict with the authenticated principal, and log the mismatch as a security-relevant failure. Capability claims MUST NOT expand the scope granted to the authenticated principal.	MUST: gateway-level reconciliation of _meta claims against federated workload identity, with alerting on claim/principal divergence

Control	L1	L2	L3	L4
Client-held state integrity	Not required	MUST: state sealed by the server and echoed back by the client, such as requestState, MUST be integrity-protected with an HMAC or AEAD and MUST be rejected when verification fails. Clients MUST NOT inspect, parse, or modify it.	MUST: the authenticated principal, an expiry, and an identifier for the originating request are sealed inside the protected payload and verified on receipt, without the specification's exemption for state whose tampering can only cause request failure. Where single-use semantics are required, servers enforce them server-side.	MUST: centrally managed and rotated sealing keys, with verification failures alerted as tampering attempts
Server and authorization discovery	Not applicable (local)	SHOULD: support server/discover and OAuth Protected Resource Metadata (RFC 9728) for server and authorization server discovery	MUST: MCP servers implement server/discover for protocol ver-sions/capabilities and expose Protected Resource Metadata for authorization server discovery. Clients should support incremental scope elevation via WWW−Authenticate challenges.	MUST: server/discover, Protected Resource Metadata, and OIDC Discovery validation with centralized policy enforcement

Control	L1	L2	L3	L4
Elicitation security	Not required	SHOULD: treat server-provided prompts and elicitation requests as untrusted. Servers must not use form mode to request credentials.	MUST: InputRequiredResult and task input_required flows isolated from privileged tool invocation unless policy explicitly allows coupling and logs it	MUST: elicitation-originated content treated as untrusted input requiring full validation before influencing tool parameters or execution
Deprecated feature migration	Not required	SHOULD: avoid new dependencies on Roots, Sampling, and protocol Logging	MUST: migrate Roots to tool parameters/resource URIs/server configuration, Sampling to direct LLM provider integration, and Logging to stderr or OpenTelemetry	MUST: deprecated feature usage centrally inventoried, exception-approved, and removed within lifecycle deadlines
Refresh tokens	Not applicable	If issued, must be protected as confidential credentials and should be rotated	MUST: refresh tokens rotated, stored securely, and not treated as substitutes for runtime authorization at the MCP server	MUST: refresh token rotation enforced, with revocation propagated within defined SLA

Threat coverage: MCP-T1 (Identity/Auth Failures), MCP-T6 (Integrity/Verification Controls), MCP-T7 (Session/Transport Failures) **OWASP MCP mapping:** MCP01 (Token Mismanagement), MCP07 (Insufficient Auth)

3.3.3 Threat Coverage Summary

This matrix shows the minimum expected coverage per threat category at each level. OWASP MCP Top 10 categories are cross-referenced where applicable.

CoSAI Threat Category	OWASP MCP Top 10	L1	L2	L3	L4
MCP-T1: Identity/Auth Failures	MCP01, MCP07	Partial	MUST	MUST	MUST
MCP-T2: Authorization Errors	MCP02, MCP07	Partial	MUST	MUST	MUST

CoSAI Threat Category	OWASP MCP Top 10	L1	L2	L3	L4
MCP-T3: Input Validation Failures	MCP03, MCP05, MCP06	SHOULD	MUST	MUST	MUST
MCP-T4: Data/Control Boundary Failures	MCP03, MCP06	Partial	MUST	MUST	MUST
MCP-T5: Data Protection	MCP10	Partial (mock data)	MUST	MUST	MUST
MCP-T6: Integrity/Verification	MCP03, MCP04	Not required	SHOULD	MUST	MUST
MCP-T7: Session/-Transport Failures	MCP01	SHOULD (localhost)	MUST	MUST	MUST
MCP-T8: Network Binding Failures	MCP09	MUST (localhost bind)	MUST	MUST	MUST
MCP-T9: Trust Boundary Failures	MCP02	Partial	MUST	MUST	MUST
MCP-T10: Resource Management	–	Not required	MUST	MUST	MUST
MCP-T11: Supply Chain Failures	MCP04	Not required	SHOULD	MUST	MUST
MCP-T12: Logging Gaps	MCP08	Not required	MUST	MUST	MUST

3.3.4 Deployment Pattern Mapping

Deployment Pattern	Typical Level	Notes
DP1: All-Local (stdio)	Level 1 or 2	Level 1 for personal experiments. Level 2 if handling internal data or if multiple users share the environment.
DP2: Single-Tenant Hybrid	Level 2 or 3	Level 2 for internal tools. Level 3 when serving production workloads or sensitive data.

Deployment Pattern	Typical Level	Notes
DP3: Multi-Tenant Cloud	Level 3 or 4	Level 3 for standard SaaS. Level 4 when regulatory obligations apply or tenant isolation failures have material consequences.

Deployment pattern alone does not determine the level. A local deployment (DP1) processing regulated health data should target Level 3 or higher regardless of its network topology. The level is a function of data sensitivity, blast radius, and regulatory context, not where the server runs.

3.3.5 Applying Profiles in Practice

Assurance levels define minimum viable security for specific deployment contexts. Organizations should select the appropriate tier based on data sensitivity and threat model, not treat Level 4 as a universal target.

Token binding is a hard requirement at Level 3. Without sender-constrained tokens, a compromised agent context, explicit state handle, or task workflow can be replayed against downstream services. Teams operating at Level 3 without DPoP or mTLS binding are accepting a risk that contradicts the level's stated trust assumptions.

Level 1 is data isolation, not "no security." Level 1 does not require runtime process sandboxing (containers, chroot), but it prohibits access to production credentials, live data, and production endpoints. If a Level 1 deployment touches real credentials, it is miscategorized. This is a classification decision, not a configuration knob.

Level transitions should be planned, not reactive. A proof-of-concept that succeeds at Level 1 will be pushed toward production. Upgrading from Level 2 to Level 3 requires migrating from standard OAuth tokens to sender-constrained tokens (DPoP), implementing workload identity (e.g., SPIFFE / SPIRE SVIDs), enforcing TBAC on tool execution, and enabling continuous ABAC evaluation.

OWASP secure MCP server guide as a Level 2 prerequisite. A Practical Guide for Secure MCP Server Development (OWASP Gen AI Security Project, 16 February 2026) defines strict deployment gates across five categories (identity, isolation, tooling, validation, deployment). Fulfilling those requirements is the prerequisite for achieving Level 2. Organizations that cannot pass that baseline should not deploy MCP servers in shared environments.

Agent gateways for Level 3 and Level 4. Embedding complex authorization, payload inspection, and identity management logic directly into individual MCP servers creates inconsistent security posture. Deployments targeting Level 3 and above should deploy a centralized proxy or agent gateway as the primary enforcement point for token validation, TBAC policy evaluation, workload identity exchange, and audit logging. Decoupling enforcement from tool execution ensures uniform compliance across heterogeneous server implementations.

Profiles can be verified. Each control in the matrix is testable. Future work should define automated checks (similar to SLSA verification tooling and tools like mcp-scan / agent-scan v0.5.15; verify the release signature or commit hash before use) that validate whether a deployment meets a claimed level. Continuous verification is critical: a server deployed securely on Tuesday may be compromised via an upstream dependency update by Thursday. Level 3 deployments should integrate continuous scanning into deployment pipelines. Level 4 deployments should enforce binary authorization blocking servers without current signed SBOMs.

3.3.6 Emerging Standards

The agent identity and authorization landscape is evolving rapidly. The following standards and frameworks are informative references for implementers. As these mature, future profile revisions will incorporate them where appropriate.

- AI Agent Authentication and Authorization (draft-klrc-aiagent-auth-01, Kasselman et al., March 2026): Proposes a comprehensive model using WIMSE architecture, SPIFFE identifiers, and OAuth extensions. Standardizes agents as workloads within the WIMSE framework. Relevant to the identity controls at Levels 3 and 4.
- OAuth Identity and Authorization Chaining (draft-ietf-oauth-identity-chaining-08, Schwenkschuster et al., 9 February 2026): Formalizes cross-domain delegation, extending RFC 8693 token exchange for multi-hop agent chains. Relevant to scope narrowing and delegation depth controls.
- Transaction Tokens for A2A (draft-liu-oauth-a2a-profile-00): Provides an alternative to nested act claims for preserving call chain context in agent-to-agent communication. May address token size concerns in deep delegation chains.
- OAuth SPIFFE Client Authentication (draft-ietf-oauth-spiffe-client-auth-00): Profiles SPIFFE SVIDs as OAuth client credentials, enabling agents to authenticate without client secrets. Relevant to Level 3+ credential management.
- AGNTCY (Linux Foundation): Provides reference implementations for Agent Identity Badges and TBAC. The TBAC model is referenced in the authorization controls at Level 3+. See #47 and #48 for evaluation threads.
- **Post-Quantum Cryptography (NIST FIPS 203/204):** NIST has standardized ML-KEM (FIPS 203) for key encapsulation and ML-DSA (FIPS 204) for digital signatures. The US federal government requires CNSA 2.0 algorithm support for newly procured National Security Systems from January 2027, with full migration by 2033–2035. For MCP deployments, hybrid key exchange (X25519 + ML-KEM-768) is the current recommended approach for transport security, and ML-DSA replaces RSA/ECDSA for server identity signatures. See the companion addendum, *Quantum-Resistant AI Infrastructure: Implementing Post-Quantum Cryptography in MCP Architectures*, for data classification guidance, implementation examples, and a migration roadmap.

3.3.7 Open Questions

1. **Granularity within levels.** Some organizations may need finer distinctions within Level 3 (e.g., "production with PII" vs. "production without PII"). Should sub-levels be supported, or should the matrix stay at four tiers with policy-level refinements handling the edge cases?
2. **SIG alignment.** The agent lifecycle SIG discussion is exploring similar profile concepts for all agent types, not just MCP. These profiles should stay compatible with that broader direction. If the SIG adopts a different level taxonomy, this matrix should be updatable without structural rework.
3. **Regulatory mapping.** Level 4 currently describes regulatory scope in general terms. A dedicated regulatory compliance annex mapping specific obligations (California AI Transparency Act, EU AI Act, sector-specific requirements) to profile controls may be warranted as a separate deliverable.
4. **Evidence-per-level annex.** A one-page reference showing expected verification artifacts at each level (server discovery response, Protected Resource Metadata endpoint, token audience validation test, issuer validation test, tool-definition hash manifest, sandbox config, egress policy, sample audit record, extension inventory entry, SBOM attestation, decommis-

sioning proof) would make the profiles more actionable for audit teams. Deferred to a follow-up.

5. **Extension risk taxonomy.** The 2026-07-28 release formalizes Extensions and includes MCP Apps and Tasks. The profiles now include baseline extension controls, but a future annex should define extension-specific review depth for sandboxed UI, durable task handles, extension versioning, delegated maintainers, and experimental extensions.

4. Conclusion

MCP adoption is accelerating, and security must keep pace. Our analysis reveals common vulnerabilities in deployments that lack adequate authentication, explicit state management, and supply chain controls. Incidents in adjacent AI systems demonstrate these are active threats, not theoretical concerns.

Organizations deploying MCP-based systems must develop defense-in-depth strategies including zero-trust architectures, hardware-based isolation through trusted execution environments, rigorous supply chain vetting, and continuous monitoring. Organizations processing data with long operational lifespans should also begin planning for post-quantum cryptographic migration; see the companion addendum *Quantum-Resistant AI Infrastructure* for implementation guidance. Securing MCP deployments requires coordinated effort across developers, organizations, and protocol maintainers—investment in security architecture now will pay dividends as agentic systems become more prevalent.

5. Contributors and Acknowledgements

Workstream Leads

- Sarah Novotny, (sarah.novotny@gmail.com)
- Ian Molloy, IBM (molloyim@us.ibm.com)
- Raghu Yeluri, Intel (raghuram.yeluri@intel.com)
- Alex Polyakov, Adversa AI (alex@adversa.ai)

Editors

- Daniel Rohrer, NVIDIA (drohrer@nvidia.com)
- Jenn Newton, Anthropic (jenn@anthropic.com)
- David LaBianca, Google (ddlb@google.com)

Contributors

- Shrey Bagga, Cisco (sbagga@cisco.com)
- Damian Bogel, Google (kele@google.com)
- Florencio Cano, Red Hat (fcanogab@redhat.com)
- John Cavanaugh, ProCap360 (johncavanaugh@procap360.com)
- Jason Clinton, Anthropic (j@anthropic.com)
- Andre Elizondo, Wiz (andre.elizondo@wiz.io)
- Riggs Goodman III, Amazon (goriggs@amazon.com)
- Hani Jamjoom, IBM (jamjoom@us.ibm.com)
- Nik Kale, Cisco (nikkal@cisco.com)
- Chooi Low, Dell (Chooi.Low@dell.com)

- Victor Lu (victorjunlu@gmail.com)
- Michael Medeiros, Cisco (mimedeir@cisco.com)
- Grant Miller, IBM (millerg@us.ibm.com)
- David Pierce, PayPal (davpierce@paypal.com)
- Shriti Priya, IBM (shritip@ibm.com)
- Xiaokui Shu, IBM (xiaokui.shu@ibm.com)
- Bill Stout, ServiceNow (bill.stout@servicenow.com)
- Moin Syed, Anthropic (moin@anthropic.com)
- Josiah Hagen, TrendMicro (josiah_hagen@trendmicro.com)
- Jonathan Whitson (jonathan_whitson@dell.com)
- Marina Zeldin, Dell (marina.zeldin@dell.com)
- Giulio Zizzo, IBM (giulio.zizzo2@ibm.com)

Technical Steering Committee Co-Chairs

- Akila Srinivasan, Anthropic (akila@anthropic.com)
- J.R. Rao, IBM (jrrao@us.ibm.com)

6. Appendix

6.1 Deployment Pattern (DP) Security Considerations

The following section examines the common deployment patterns and their security implications in more detail.

6.1.1 Deployment Pattern 1: All-Local

MCP Client: localhost
MCP Server: localhost
Transport: stdio | http

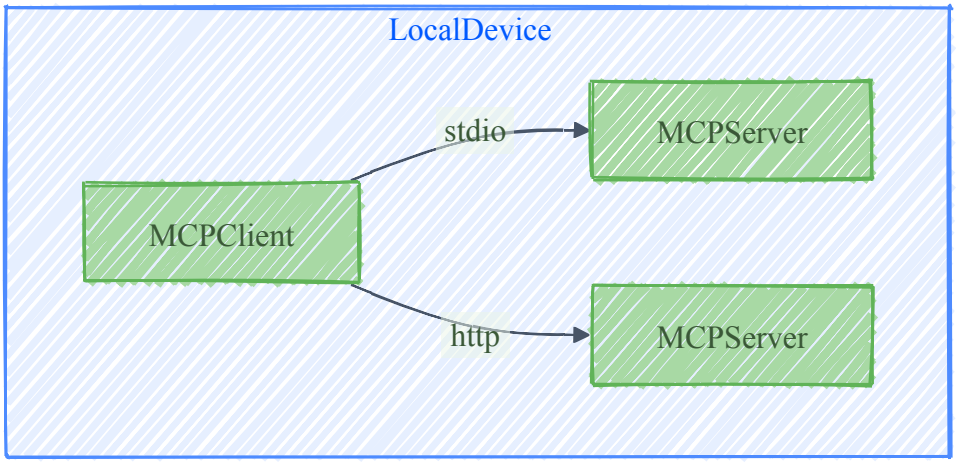


Figure 2: *DP1: All Local*

All-local deployment security is entirely dependent on the host system's posture and a general-purpose desktop or laptop with standard user software, internet connectivity, and physical access exposes the MCP server to the same attack vectors: malware execution, credential theft, supply

chain compromise through installed packages, and physical device access.

With stdio transport, the MCP server runs as a subprocess of the host application, typically sharing the same user privileges and security context. This model trades network segmentation and centralized security controls for simplicity and direct access to local tools. It is well-suited for development workflows, trusted personal tools, and scenarios requiring direct local system access. However, for production deployments handling sensitive data or serving multiple users, the lack of isolation and dependence on host security may be insufficient depending on organizational risk tolerance and compliance requirements.

Security Implications:

- Exposes local system to potentially malicious or compromised servers
- Execution control: Inherits host's security posture
- Data access control: inherits host's data posture

Security Recommendations:

- Appropriate for development and personal use
- Use stdio to avoid DNS rebinding risks: stdio transport is strongly recommended for local MCP as this eliminates DNS rebinding risks that can occur with HTTP-based transports on local servers
- Use sandboxing to limit privilege escalation attacks: running MCP servers locally requires a sandbox to prevent privilege escalation attacks

6.1.2 Deployment Pattern 2: Single-Tenant Hybrid

MCP Client: localhost
MCP Server: single-tenant remote host
Transport: http

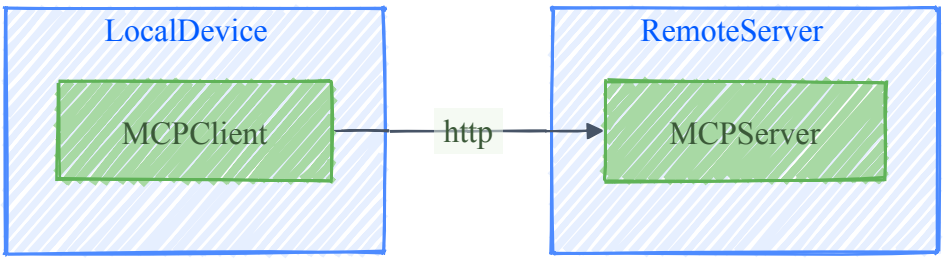


Figure 3: *DP2: Single-Tenant Hybrid*

MCP deployment model where the client runs locally but connects to a single-tenant MCP server in the cloud. Provides users with local tools (file access, development utilities) and remote capabilities (API access, shared resources, centralized data).

Note: Authentication between client and server **is required** to establish the trust boundary.

Security Implications:

- Security of the remote MCP server depends on cloud infrastructure controls rather than local host posture
- Client security has similar implications toDeployment Pattern1 as it is running locally

Security Recommendations:

- Secure Credential Storage: clients should use secure credential storage (OS keychains, secret managers) to protect MCP server authentication tokens

- Authenticated and Encrypted: communication between local and cloud components must be authenticated and encrypted
- Secure Servers and Discovery: enterprise clients should enforce authenticated server discovery and maintain explicit allowlists (ex. via MDM)

6.1.3 Deployment Pattern 3: Multi-Tenant Cloud

MCP Client: cloud-hosted or locally-hosted
MCP Server: PaaS or SaaS provided
Transport: http

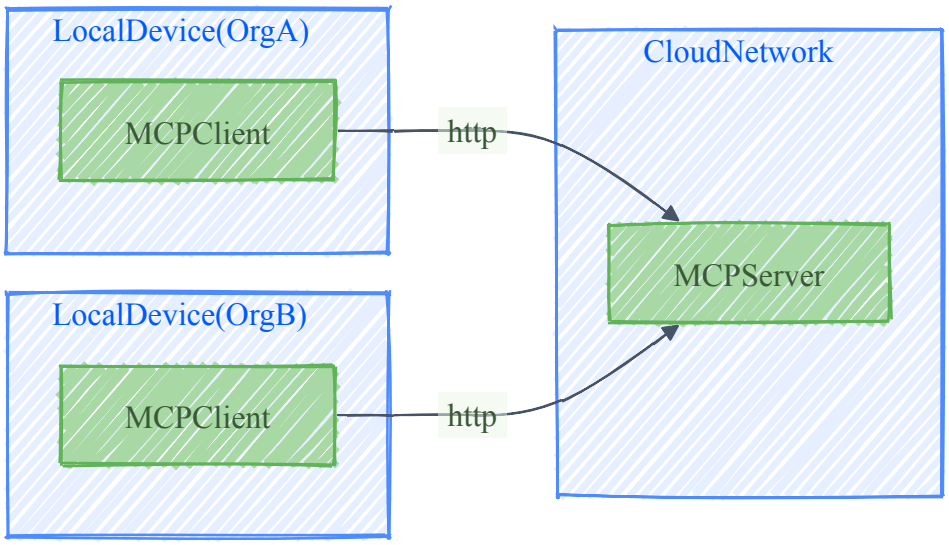


Figure 4: *DP3: Multi-Tenant Cloud*

An MCP deployment model where a service provider runs an MCP server and provides access to multiple tenants. The MCP server could serve its own tools, prompts, and resources or provide an MCP tool interface to an existing service, API, or application.

Security Implications:

- Requires robust tenant isolation, identity, and access control
- Improper isolation may lead to leakage of sensitive data or privilege escalation

Security Recommendations:

- MCP server developers must implement strong multi-tenancy controls (e.g., per-tenant encryption, RBAC).
- Select MCP servers hosted directly by the service provider (e.g., use GitHub's MCP server for GitHub access instead of a third-party server)
- Provide remote attestation for MCP servers when possible

6.2 Threat Details

MCP-T1: Improper Authentication and Identity Management

Technical Description: Absence of authentication mechanisms, insecure credential storage practices, inadequate identity verification, and weak issuer validation within MCP implementations. The protocol's optional authentication model combined with the common practice of storing multiple service credentials (OAuth tokens, API keys, database passwords) in centralized

MCP servers creates high-value targets. MCP servers may accumulate credentials without cryptographic protection, secure storage standards, credential rotation policies, or binding to the authorization server that issued them. Removal of the protocol-level session moves identity assertion into per-request _meta, so every request now restates who the caller claims to be in a field the caller controls; a server that reads client identity or capabilities from _meta without reconciling them against the authenticated principal will accept impersonated requests. See the official MCP documentation for additional guidance.

Architectural Impact: Improper agent identity and authentication leads to impersonation and replay attacks, preventing the MCP server and endpoints from correctly identifying the identity of the originating request, and a confused deputy. The insecure storage of authentication credentials across users and services fundamentally alters the security posture. Weak or absent authentication enables unauthorized server access, credential harvesting, token theft, and persistent access.

Vulnerability Examples: Credential exposure in configuration files, OAuth token theft, authentication bypass, lack of multi-factor authentication, insecure credential storage, static client ID vulnerabilities, authorization server mix-up, missing RFC 9207 iss validation, unreconciled _meta identity or capability claims, authentication mechanism implementation flaws

MCP-T2: Missing or Improper Access Control

Technical Description: Absence of authorization mechanisms, improper enforcement of object-level permissions, and insufficient capability-based access control within MCP deployments. MCP servers commonly request and receive overly broad permission scopes to maximize flexibility, while implementations fail to verify user permissions for individual objects, resources, tools, extension capabilities, or operations. The 2026-07-28 release's explicit scope challenge and step-up procedures reduce some overbroad consent pressure, but only when clients preserve prior scopes correctly and servers issue precise WWW−Authenticate challenges.

Architectural Impact: Enables unauthorized data access, privilege escalation, and lateral movement across connected services. The optional nature of authorization combined with developers' tendency to grant excessive permissions leads to inconsistent security postures

Vulnerability Examples: Broken Object Level Authorization (BOLA), privilege abuse, overbroad permissions, insufficient authorization checks, context bleeding, cross-tenant data exposure, function-level access control failures, configuration file exposure.

MCP-T3: Input Validation/Sanitization Failures

Technical Description: Absence of input validation, sanitization, and parameterization across multiple injection contexts including command execution, database queries, file system operations, and serialization boundaries. This vulnerability class encompasses traditional injection flaws exacerbated by the false sense of security provided by AI mediation. Developers incorrectly assume that user input processed through an LLM is inherently safe, bypassing established secure coding practices, when in reality the LLM transforms but doesn't sanitize malicious payloads.

Architectural Impact: Enables command injection, SQL injection, LDAP injection, XML injection, path traversal, and deserialization attacks with potentially catastrophic consequences. Can be combined with other threats (MCP-T4) for increased impact.

Vulnerability Examples: Command injection, SQL injection, remote code execution (RCE), path traversal, LDAP injection, XML injection, deserialization vulnerabilities, unsafe file operations

MCP-T4: Data/Control Boundary Distinction Failure

Technical Description: This design limitation enables the entire class of prompt injection vulnerabilities, including direct injection, indirect injection through tool / schema descriptions, and context manipulation attacks. LLMs lack syntactic or semantic mechanisms to differentiate between control instructions and data payloads. This fundamental limitation stems from the continuous token stream processing model, where both trusted system prompts and untrusted user data are processed within the same computational context without clear demarcation. The absence of a control plane/data plane separation at the architectural level means any adversary-controllable input—including tool responses, schema descriptions, and resource content—can potentially alter the execution flow of the AI system.

Architectural Impact: Attackers can embed malicious instructions in seemingly benign content (emails, documents, API responses) that, when processed by the LLM, execute unauthorized actions. The blurring of boundaries between viewing content and executing commands creates attack vectors where reading a document can trigger data exfiltration, system compromise, or unauthorized API calls through MCP tools.

Vulnerability Examples: Prompt injection (direct and indirect), tool poisoning attack (TPA), full schema poisoning (FSP), advanced tool poisoning attack (ATPA), resource content poisoning, hidden prompt embedding (Unicode attacks), malicious message crafting.

MCP-T5: Inadequate Data Protection and Confidentiality Controls

Technical Description: Insufficient encryption, inadequate secrets management, and absence of data protection standards for sensitive information in transit, at rest, and during processing. MCP implementations commonly expose personally identifiable information (PII), financial data, and intellectual property without proper encryption, data classification, or access segmentation.

Architectural Impact: Creates significant data exposure risks where attackers gaining partial access can perform correlation attacks across services to build comprehensive user profiles, enabling sophisticated spear-phishing, extortion, or identity theft. The concentration of access to disparate services in a single protocol layer violates the security principle of segregation, allowing data leakage through logging, error messages, debug output, and traffic inspection. Without encryption and proper secrets management, sensitive data remains vulnerable throughout its lifecycle.

Vulnerability Examples: Unencrypted credential storage, sensitive data exposure in logs, PII leakage

MCP-T6: Missing Integrity/Verification Controls

Technical Description: Absence of cryptographic integrity verification mechanisms for MCP servers, clients, tool definitions, message authenticity, configuration immutability, and behavioral attestation. The protocol lacks provisions for code signing, integrity verification, message authentication codes, reproducible builds, and tamper-evident logging, enabling undetected modification of critical system components. Permits tool behavior mutation, configuration tampering, message forgery, launch and execution of compromised/shadow MCP servers and clients and supply chain attacks.

Architectural Impact: Without integrity verification, malicious actors can modify tool definitions post-deployment, alter configuration files after approval, and inject malicious updates without detection

Vulnerability Examples: Rug Pull Attack, Tool Shadowing, Tool Name Spoofing, MCP Configuration Poisoning

MCP-T7: Session and Transport Security Failures

Technical Description: Systematic weaknesses in state lifecycle management and transport security. In legacy MCP versions this included insecure Mcp−Session−Id transmission, weak session binding, insecure session storage, and inadequate session termination controls. In the 2026-07-28 release, protocol-level sessions are removed, shifting the risk to capability-bearing references (task IDs, continuation handles, requestState), cache entries, and per-request _meta validation. Two failures are specific to this shift. Durable task execution can outlive the grant that authorized it, because the server continues the work between client polls and no request gates it. Separately, a server that accepts both the legacy and stateless models exposes a downgrade path to the legacy authorization flow, which established authorization once at initialize rather than per request. The transport layer still requires strong encryption, origin protections, header/body consistency checks, and robust cancellation behavior.

Architectural Impact: Enables state-handle hijacking, replay attacks, stale-cache use, man-in-the-middle attacks, header/body confusion, and cross-site request forgery.

Vulnerability Examples: Legacy session management flaws, explicit handle leakage, task ID enumeration, tampered client-held sealed state accepted without integrity verification, tasks continuing to execute under a revoked grant, protocol version downgrade to legacy session authorization, replay attacks, insufficient timeout policies, man-in-the-middle attacks, insecure transport protocols, Mcp−Method / Mcp−Name mismatch handling failures

MCP-T8: Network Binding/Isolation Failures

Technical Description: Architectural deficiencies in network isolation including improper network interface binding, absence of network segmentation requirements, vulnerability to DNS rebinding attacks, and lack of defense-in-depth network controls. MCP implementations commonly bind to all available interfaces (0.0.0.0) rather than localhost, exposing internal services to external networks. The protocol lacks specifications for network-level security boundaries, proper CORS policies, and protection against cross-origin attacks.

Architectural Impact: Exposes internal services to external networks, enables lateral movement within compromised environments, and permits DNS rebinding attacks that bypass same-origin policies.

Vulnerability Examples: Localhost bypass (NeighborJack), DNS rebinding attacks, improper network interface binding, insufficient network segmentation, cross-origin vulnerabilities, exposure of internal services, lateral movement exploitation

MCP-T9: Trust Boundary and Privilege Design Failures

Technical Description: Fundamental architectural flaw wherein the protocol assumes an optimistic trust model between the MCP client and server or an MCP server and third-party API or service.

Architectural Impact: Creates cascading security failures where compromise of a single component leads to complete system breach. Enables privilege escalation, lateral movement across service boundaries, and complex attack chains exploiting transitive trust relationships.

Vulnerability Examples: Overreliance on an LLM, confused deputy, cross-tenant exposure, overreliance on human-in-the-loop

MCP-T10: Resource Management/Rate Limiting Absence

Technical Description: Lack of resource consumption controls, quota management systems, and economic attack prevention mechanisms. MCP deployments still require local controls for token limits, context size boundaries, API call quotas, computational resource allocation, cache storage, task concurrency, polling frequency, and cost management, enabling resource exhaustion and

economic denial-of-service attacks when absent.

Architectural Impact: Facilitates denial-of-service through token exhaustion, context window overflow, and API quota depletion. Enables economic attacks where minimal attacker investment causes disproportionate financial damage through excessive LLM API consumption. The absence of resource controls can lead to unexpected costs, high latency, and denial of service.

Vulnerability Examples: Denial of Wallet, Denial of Service, MCP Resource Exhaustion, MCP Recursive Task Exhaustion, long-running task accumulation, excessive tasks/get polling, Large Context Payload DoS

MCP-T11: Supply Chain and Lifecycle Security Failures

Technical Description: Absence of secure software supply chain practices for MCP server acquisition, installation, updates, and lifecycle management. The protocol lacks standardized mechanisms for verifying server provenance, validating package integrity before installation, or maintaining inventory of deployed MCP servers across an organization. MCP servers are commonly downloaded from third-party repositories without cryptographic verification, installed without security review, and remain operational indefinitely without lifecycle management. Organizations face risks from shadow MCP servers deployed without authorization, zombie servers that remain active after deprecation, and malicious packages masquerading as legitimate tools in public repositories.

Architectural Impact: Creates pre-deployment and operational security gaps distinct from runtime integrity issues. Attackers can distribute malicious MCP servers through popular repositories, compromise legitimate packages during distribution, or exploit the absence of inventory management to deploy unauthorized servers. Shadow deployments bypass security controls entirely, and the absence of centralized inventory prevents detection of unauthorized MCP infrastructure across the enterprise.

Vulnerability Examples: Malicious MCP package distribution, compromised package repositories, shadow server deployments, zombie/deprecated servers, typosquatting in package names, package substitution attacks, unsigned server distributions, unvetted community packages, lack of security review processes

MCP-T12: Insufficient Logging, Monitoring, and Auditability

Technical Description: Absence of standardized audit logging, comprehensive traceability mechanisms, and security monitoring capabilities within MCP implementations. Without robust logging of MCP server requests, request metadata, tool invocations, extension use, authorization decisions, task lifecycle events, cache decisions, and data access patterns, organizations face significant compliance blind spots and inability to perform forensic analysis of security incidents. The deprecated MCP Logging feature should not be treated as the security telemetry plane; use structured logs and OpenTelemetry instead.

Architectural Impact: Severely impairs incident detection, response capabilities, and post-incident forensics. Organizations cannot trace AI agent actions back to their source, establish accountability for security breaches, or identify patterns indicating compromise or abuse. Compliance frameworks requiring audit trails and accountability mechanisms cannot be satisfied, creating regulatory risks and limiting the ability to meet security certification requirements.

Vulnerability Examples: Insufficient audit logging, lack of security telemetry, inability to trace attack chains, missing W3C Trace Context propagation, missing forensic capabilities, inadequate anomaly detection, undetected shadow servers, compliance violations, absence of accountability mechanisms, blind spots in security visibility

6.3 MCP Threats and Vulnerabilities

6.3.1 Conventional Security

16. **Credential Theft /Token Theft** Attackers exploit insecure storage, handling, or transmission of secrets (OAuth tokens, API keys, credentials), enabling impersonation, unauthorized access, or privilege escalation.
17. **Replay Attacks/Session or Handle Hijacking** Attackers intercept, reuse, or hijack authentication tokens, legacy session identifiers, explicit state handles, task IDs, or request continuation state, impersonating legitimate users or agents and executing unauthorized actions.
18. **OAuth/Legacy Auth Weaknesses** Use of outdated, weak, or pass-through authentication and authorization (e.g., basic auth, static API keys) exposes systems to impersonation, privilege misuse, and poor accountability.
19. **Session, Token, or Handle Leakage** Exposure or insecure handling of tokens, legacy session identifiers, task IDs, or explicit state handles across MCP components leads to unauthorized access, impersonation, or replay.
20. **Excessive Permissions/Overexposure** AI agents, MCP servers, or tools are granted more privileges than necessary, increasing risk of abuse or compromise in case of attack or misconfiguration.
21. **Command Injection** Unvalidated or unsanitized user inputs, prompts, or tool arguments lead to execution of unauthorized system commands, resulting in data compromise or system takeover.
22. **File System Exposure/Path Traversal** Improper validation of file paths or tool arguments enables access to or exfiltration of files outside intended directories, exposing credentials and sensitive data.
23. **Insufficient Integrity Checks** Absence of signature or integrity validation on MCP messages and responses enables replay, spoofing, or delivery of poisoned results.
24. **Data Exfiltration & Corruption** Attackers leverage MCP components to steal or corrupt sensitive data, reroute messages, or manipulate outputs, often via compromised servers or poisoned tools.
25. **Supply Chain Compromise** Malicious or compromised MCP servers, dependencies, or packages are introduced into the environment, enabling attackers to execute arbitrary code, exfiltrate data, or persist within the infrastructure.
26. **Unrestricted Network Access** MCP servers or clients with open outbound or inbound network access can download malicious payloads, exfiltrate data, or connect to command-and-control infrastructure. Malicious or compromised MCP servers allow attackers to move laterally using stored credentials and exploiting poor network segmentation and isolation.
27. **Protocol Security Gaps** Weaknesses in MCP protocol/transport layers (e.g., missing payload limits, no TLS, unauthenticated requests) enable DoS, spoofing, or unauthorized command execution.
28. **Insecure Descriptor Handling** Improper management of transport descriptors (e.g., stdio) allows attackers to hijack or interfere with data streams and process communications.
29. **CSRF Protection Missing** Lack of Cross-Site Request Forgery (CSRF) controls on HTTP and Streamable HTTP transports enables attackers to forge or replay unauthorized requests.
30. **CORS/Origin Policy Bypass** Missing or weak cross-origin policies allow unauthorized data leaks via cross-origin resource sharing (CORS) in browser-based or web transports.
31. **Malicious Command Execution** Compromised or rogue MCP servers execute arbitrary or malicious payloads (ransomware, data manipulation) triggered by crafted prompts or files.
32. **Dependency/Update Attack** Attackers compromise MCP dependencies or update channels (e.g., "rug pull" attacks), swapping benign code for malicious versions after trust is established. MCP servers may also introduce new capabilities (e.g., tools or prompts) that have not been vetted or approved for use.
33. **Payload Limit/DoS** Unrestricted payload sizes or recursion depth in protocols enable denial-

of-service via resource exhaustion.

34. **Lack of Observability** Insufficient logging, monitoring, tracing, or attribution across MCP actions hides malicious or unintended activity, hindering detection and response.

6.4 CoSAI Focus

CoSAI is an OASIS Open Project, bringing together an open ecosystem of AI and security experts from industry-leading organizations. The project is dedicated to sharing best practices for secure AI deployment and collaborating on AI security research and product development. The scope of CoSAI is specifically focused on the secure building, integration, deployment, and operation of AI systems, with an emphasis on mitigating security risks unique to AI technologies. Other aspects of Trustworthy AI are deemed important but beyond the scope of the project including, ethics, fairness, explainability, bias detection, safety, consumer privacy, misinformation, hallucinations, deep fakes, or content safety concerns like hateful or abusive content, malware, or phishing generation. By concentrating on developing robust measures, best practices, and guidelines to safeguard AI systems against unauthorized access, tampering, or misuse, CoSAI aims to contribute to the responsible development and deployment of resilient, secure AI technologies.

6.5 Guidelines on usage of more advanced AI systems (e.g. large language models (LLMs), multi-modal language models. etc) for drafting documents for OASIS CoSAI:

tl;dr: CoSAI contributions are actions performed by humans, who are responsible for the content of those contributions, based on their signed OASIS iCLA (and eCLA, if applicable). [Each contributor must confirm whether they are entitled to donate that material under the applicable open source license; OASIS and the CoSAI Project do not separately confirm that.] Each contributor is responsible for ensuring that all contributions comply with these AI use guidelines, including disclosure of any use of AI in contributions.

- Selection of AI systems: CoSAI recommends the use of reputable AI systems (lowering the risk of inadvertently incorporating infringing material).
- Model constraints: Currently, CoSAI or OASIS are not required to have a contract or financial agreement for using AI systems from specific vendors. However, CoSAI editors should consider employing varying tools to avoid potential fairness concerns among vendors.
- IP infringement: It is the responsibility of the individual who subscribes/prompts and receives a response from an AI system to confirm they have the right to repost and donate the content to OASIS under our rules.
- Transparency: CoSAI's goal will be to maintain transparency throughout the process by documenting substantial use of AI systems whenever possible (e.g., the prompts and the AI system used), and to ensure that all content, regardless of production by human or AI systems, was reviewed and edited by human experts. This helps build trust in the standards development process and ensures accountability.
- Human-edited content and quality control: CoSAI mandates human-reviewed or -edited results for any final outputs. A robust quality control process should be in place, involving careful review of the generated content for accuracy, relevance, and alignment with CoSAI's goals and principles. Human experts should scrutinize the output of AI systems to identify any errors, inconsistencies, or potential biases.
- Iterative refinement: The use of AI systems in drafting standards should be seen as an iterative process, with the generated content serving as a starting point for further refinement and improvement by human experts. Multiple rounds of review and editing may be necessary to ensure the final standards meet the required quality and reliability thresholds.

6.6 Copyright Notice