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# Cybersecurity — Security considerations throughout the product life cycle

*Cybersécurité — Considérations relatives à la sécurité tout au long du cycle de vie du produit*

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# Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives or www.iec.ch/members_experts/refdocs).

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 27, *Information security, cybersecurity and privacy protection*.

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# Introduction

The globalization of technology design, development, manufacturing, and distribution has created an environment of complicated supply chains with limited transparency. This presents an incredible challenge for the industry and highlights a growing need to ensure product integrity for all stages of the information and communications technology (ICT) product life cycle.

The call for assurance across the supply chain landscape has evolved over several decades. More recently, policy makers around the world have begun to focus on supply chain risks in new ways: from policies considering supply chain security risks for government procurement to various initiatives adding security considerations such as trust and transparency in the supply chain for ICT.

Vendors have been doing their part as well. Over the past several years, ICT suppliers have taken important steps towards increasing supply chain transparency. These steps include sourcing conflict-free minerals,[1] and implementing a set of policies, procedures and tools at factories to improve security consideration throughout the supply chain by validating where and when each component of an ICT product was manufactured.

These are important first steps, however they primarily focus on the production stage, just one stage of the ICT product life cycle. In today's complex environment, hardware platform providers are expected to enable a full range of tools and solutions that improve security consideration across the entire life cycle, from design and sourcing to secure retirement.

Security considerations throughout the product life cycle (SCLC) establish an end to end framework that can be applied to the multi-year life cycle of ICT products to comprehend and address potential risks for improved transparency and higher levels of security assurances. By enabling transparency and assurances across the ICT product life cycle, supply chain owners can improve platform integrity, resilience and security. The life cycle phases are both iterative and recursive in nature.


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# Cybersecurity — Security considerations throughout the product life cycle

## 1 Scope

This document describes security considerations throughout the product life cycle (SCLC), which is a framework that spans the entire information and communications technology (ICT) product life cycle. The aim of the framework is to align the industry and bring greater transparency to customers at every point on the ICT product life cycle.

This document describes the following items for suppliers, end users (consumers), intermediaries of the ICT supply chain, service providers, and regulators:

— definition of phases in the ICT product life cycle from concept to retirement;

— threat vectors possible in each phase of the life cycle;

— potential controls against those threat vectors.

The target audiences of this document are suppliers and consumers of ICT products, including all participants throughout the supply chain such as silicon chip designers, fabricators, product assemblers, logistics providers, service providers, and information security organizations. Clauses 5 to 11 target an organization's strategic and risk management teams. This document provides an end-to-end view of the threats in each phase to help the organization shape their plans, procedures and policies.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC/IEEE 15288, *Systems and software engineering — System life cycle processes*

ISO/IEC/IEEE 24748-1:2018, *Systems and software engineering — Life cycle management — Part 1: Guidelines for life cycle management*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC/IEEE 15288, ISO/IEC/IEEE 24748-1:2018, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

**3.1**
**digital signature**
data appended to, or a cryptographic transformation of, a data unit that allows the recipient of the data unit to verify the source and integrity of the data unit

[SOURCE: ISO/IEC 9798-3:2019, 3.3]

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**3.2**
**code scanner**
program source code and binary file security analysis tool

**3.3**
**hardware trojan**
malicious program or hardware that masquerades as a benign application

## 4 Abbreviated terms

| | |
|---|---|
| ASIC | application specific integrated circuit |
| BOM | bill of materials |
| CPU | central processing unit |
| DRM | digital rights management |
| DSP | digital signal processor |
| ERP | enterprise resource planning |
| FPGA | field programmable gate array |
| FW | firmware |
| HDL | hardware description language |
| HW | hardware |
| IC | integrated circuit |
| ICT | information and communication technology |
| ISV | independent software vender |
| OEM | original equipment manufacture |
| OSAT | outsourced semiconductor assembly and test |
| OS | operating system |
| PUF | physically unclonable function |
| SaaS | software as a service |
| SDL | security development life cycle |
| SoC | system on chip |
| SW | software |
| VHDL | very high-speed integrated circuit hardware description language |


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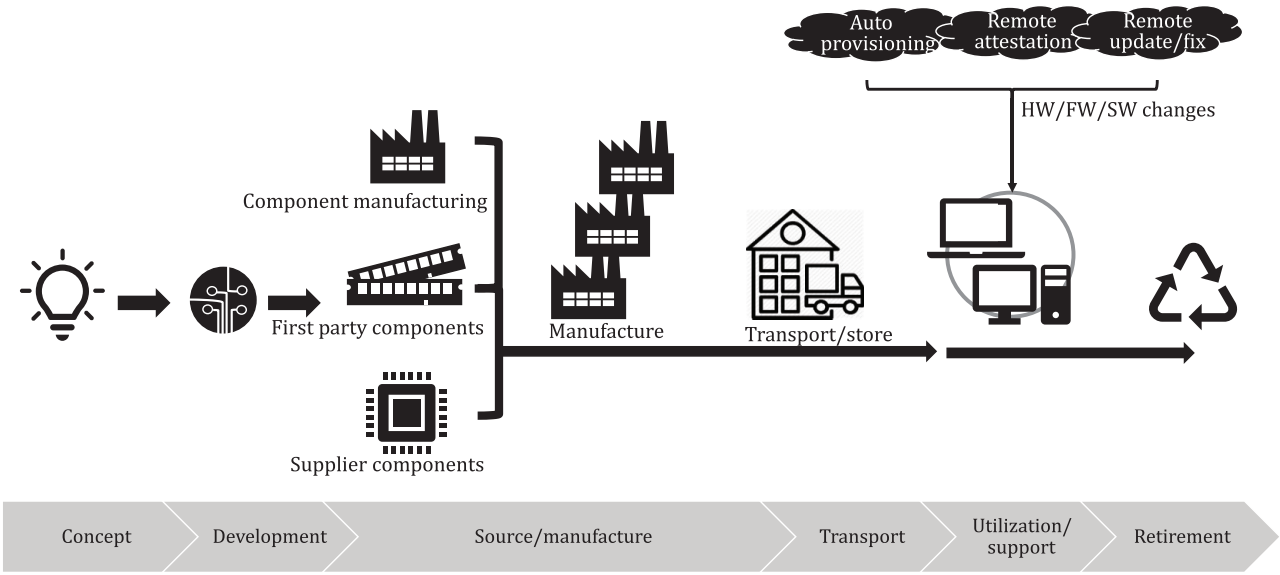


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**Figure 1 — ICT system life cycle**

# 5 Security considerations throughout the product life cycle

## 5.1 Security considerations throughout the product life cycle overview

Security considerations throughout the product life cycle (SCLC) is a framework to describe the ICT products life cycle from security assurance and manufacturing perspectives (see Figure 1). The concept of SCLC can be applied to hardware products and software such as microcode, firmware, and other software to support the hardware. SCLC consists of six common product life cycle phases which are shown in Figure 2 with typical threat vectors. The names of the phases are derived from ISO/IEC/IEEE 24748-1 and processes unique to SCLC have been added. It is important to note that each phase exists for individual components, sub-systems and end products. It is both possible and highly likely that some of the phases are executed more than once for an individual component (e.g. integrated circuits go through wafer fabrication, sorting, assembly and final test. Those facilities, if separate, introduce multiple build/transfer phases).

ISO/IEC/IEEE 15288 defines the life cycle of a system by four process groups which are 1) agreement process, 2) organizational project-enabling process, 3) technical management process and 4) technical process. Since this document describes the life cycle from a different perspective, that is, the “product life cycle”, there is no conflict or inconsistency between ISO/IEC/IEEE 15288 and this document. Another systems approach to security is the NIST SP 800-160V1 that aligns with this approach.[3]

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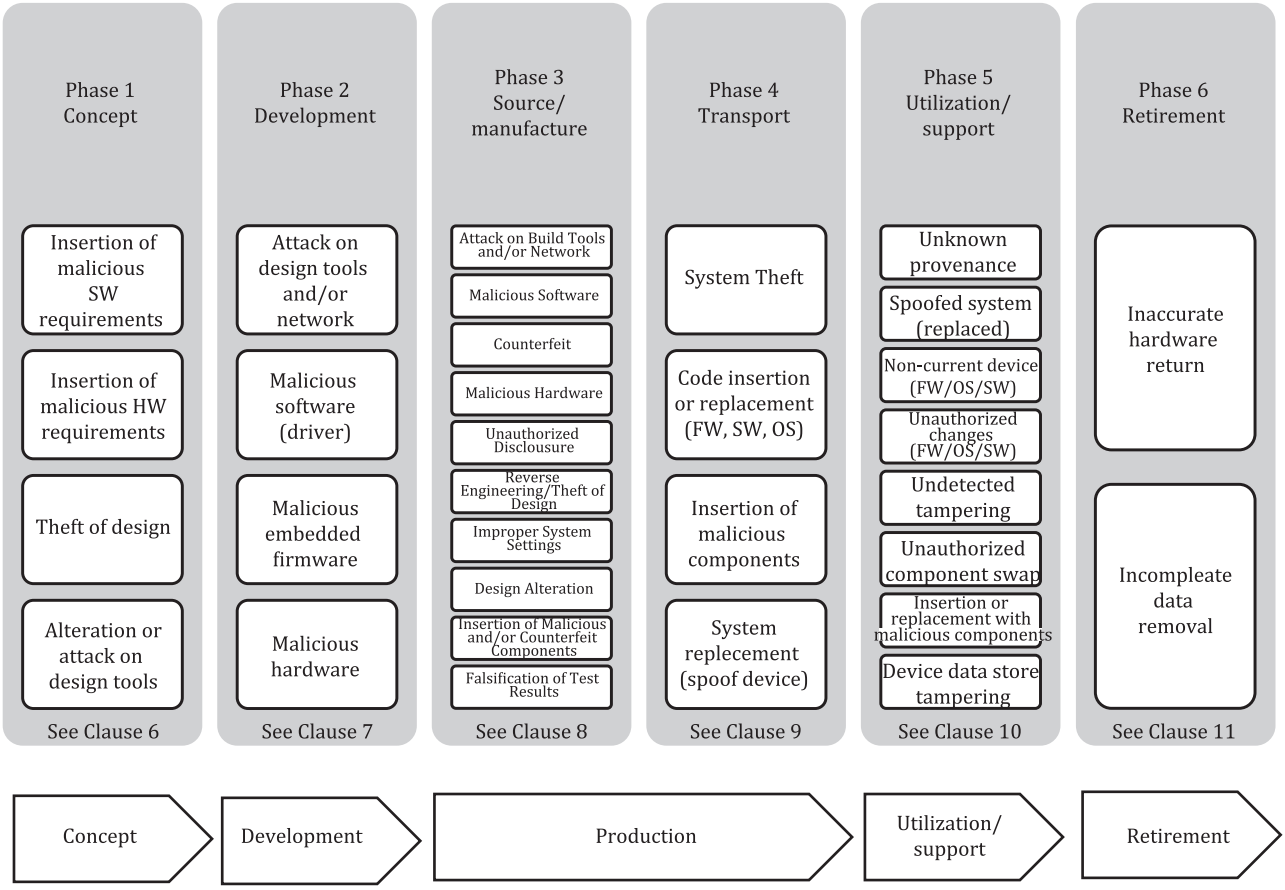


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**Figure 2 — ICT Product life cycle and threat vectors**

Figure 3 shows a relationship of technical processes in ISO/IEC/IEEE 15288 and SCLC phases.


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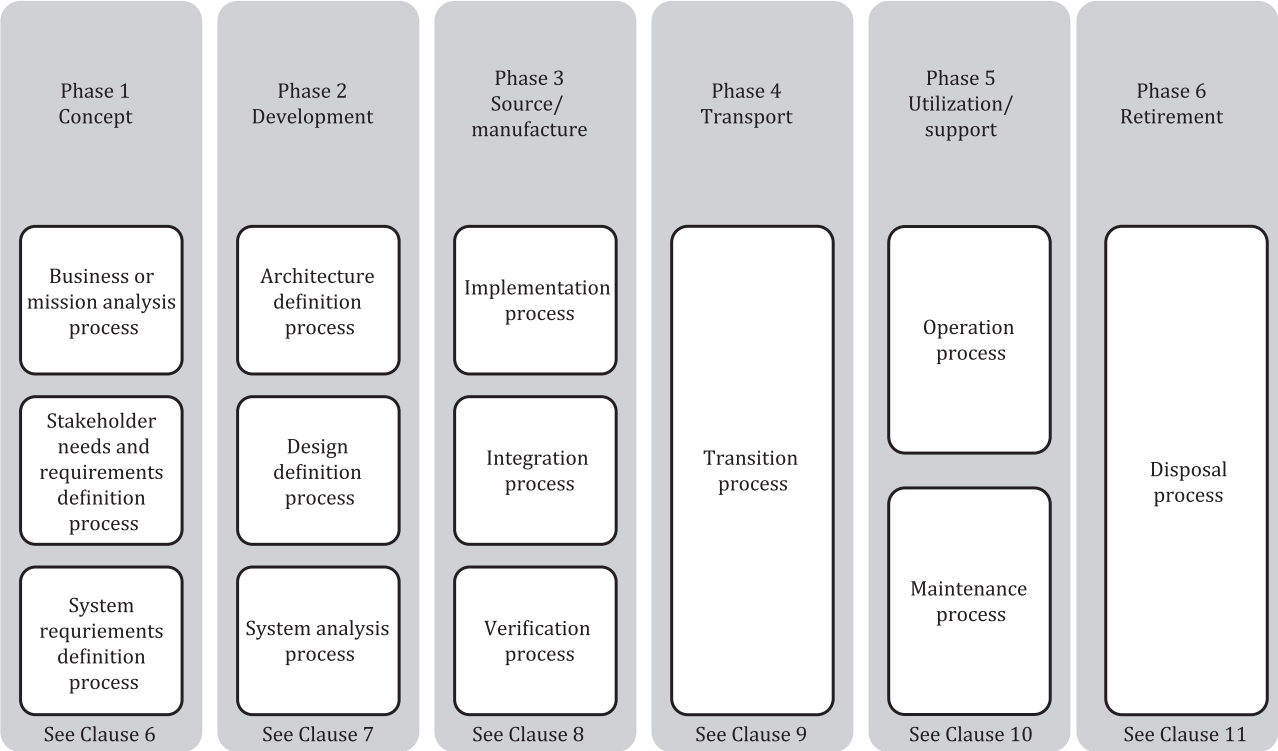


**Figure 3 — Mapping technical processes of ISO/IEC/IEEE 15288 and SCLC life cycle phases**

## 5.2 Information and communication technology threat model

Security threats against ICT products exist not only in the utilization/support phase but in all six phases shown in Figure 2.[4] Each phase has different threat vectors, but some vectors such as theft occur in multiple phases. This means responsible parties are expected to apply proper measures in each phase for each threat vector applicable.

From Clause 6 to Clause 11, the key characteristics of each ICT product's life cycle phase and typical threat vectors are described.

## 5.3 Classes of threats

There are multiple classes of security threats. The first type is an attack that targets unintentional vulnerability, such as ICT product security vulnerability in the manufacturing process or in the physical storage and transportation processes. The second type is an intentional attack by insider personnel who can access the process and change or replace tools, products, or components. The focus of this document is to identify and protect ICT products from the first type of threats. However, the methods described in this document can also be used to mitigate the risks of the second type of threats. In many cases, additional protection measures are necessary, such as employee/personnel management and access control in all phases for all stakeholders who participate in the product life cycle.

## 5.4 Structure of the report

Clauses 6 to 11 give an overview of each phase, threats, and controls. Additionally, Annexes A, B, C and D provide specific best practice procedures and controls for practitioners that they can implement within their operation to mitigate against potential threats.

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# 6 Phase 1: Concept

## 6.1 General

In the concept phase, user needs are identified, and system concepts are described and evaluated. In addition to the user needs, companies are expected to consider regulatory controls and security objectives to establish a comprehensive set of requirements to be met in development.

Given the complexity of ICT products, many companies combine internal design, third party design and open source design to deliver a single component on a system that can comprise hundreds of components. For example, the system on a chip (SoC) component can contain hardware blocks sourced from many third parties, as well as blocks designed by the product manufacturer. This complexity introduces additional risks as unneeded features from external components that are incorporated into the end product, possibly creating a vulnerability that can be attacked. For this reason, the product flows back through the concept phase to add additional security control requirements based upon decisions made in development.

It is best practice for ICT product organizations to adopt a security development life cycle (SDL) process that conforms to ISO/IEC 27034-1. This process ensures the identification of unique threats at the start of the concept phase and turns those into a set of requirements to be met during the development phase. Additionally, SDL requires the training of the engineers, designers and architects that work on how to best maintain a secure system, thereby increasing the security of the product.

SCLC in the concept phase addresses the questions:

— What is in the products function?

— Does the product contain anything additional that can be used against the owner/operator of the ICT product?

In 6.2, possible threat vectors and mitigations in this phase are described.

## 6.2 Summary of concept threats and controls

### 6.2.1 Workflow toolchain tampering

Management of the software tools used in support of the concept phase is critical to mitigating attacks to the tool that can alter the design or allow feature requirements to be stolen. These tools often support integration with third-party plugins, such as those from outside tool vendors or even from the original tool provider. If the plugins are not properly verified/certified, they can contain malicious elements. Additionally, installation of these modules can be subject to man-in-the-middle (MITM) attacks during transit over the network or in the build of the tool software by the software provider. The modules require sufficient verification before installation into the concept toolchain. It is essential to implement a practice for managing design tools and keeping them up to date and secure. Best practice ensures these plugins have been digitally signed and licensed by a reputable producer, are regularly scanned by source code scanners (static and dynamic) and have an internal team responsible for securing the design tools. Moving to a SaaS workflow toolchain vendor properly skilled in secure life cycle practices and verified by an independent third party can also be an effective way to improve controls on the toolchain. However, this comes with risks, as the SaaS providers are a likely target of attack due to the multitude of customers in one spot. The ICT product developer is responsible for securing their workflow toolchain and for assessing their own internal security controls against that of a SaaS provider to determine the best way to implement their workflow toolchain.

In cases where the network used in the concept phase is not a closed network, attacks can be launched against these networks from external adversaries in the hopes of obtaining or modifying sensitive design files. Such attacks can be supported by an insider threat that installs malware or a virus on critical security systems, allowing for easier access and attacks against target platforms. Refer to ISO/IEC 27032 for guidance on building and maintaining secure networks, as this issue is the same for any ICT entity that runs a private network.


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### 6.2.2 Unauthorized operations

The unauthorized invocation of data operations for creating, reading, updating/modifying or deleting data in the concept phase can impact the development of the product, its components or sub systems. For example, a security feature developed in concept phase, but which has been deleted/rejected or changed and which influences the product design and build to not include a security feature necessary to protect the product in operation or add a backdoor into the product for future attacks once in operation.

### 6.2.3 Integrity faults

The integrity faults can occur by unintentional modification or destruction of data due to technical or operational errors, faults or failures occurring within a product, or related to supporting the product's concept phase. Like unauthorized operations, this can lead to a manipulation or exclusion of requirements for the development phase, thereby altering the function of the ICT product. These faults can get caught in development if the appropriate test cases are in place to validate the correct requirements. However, if they are not caught, or caught too late in the life cycle, additional costs are incurred as the product is looped back into the development phase to remove the vulnerability.

### 6.2.4 Theft or loss

The absence, removal or destruction of a data asset, or unauthorized data access due to actions taken by a malicious actor, or by environmental hazards can occur within the concept phase.

# 7 Phase 2: Development

## 7.1 General

This is the second phase of the ICT product life cycle, where engineering design and development are conducted. Example processes are prototype design and evaluation, engineering sample development and manufacturing, threat analysis, manufacturing tool development and production operation planning.

## 7.2 Summary of development threats and controls

### 7.2.1 Attacks on development tools and/or network

The same security threats and prevention mechanisms described in 6.2.1 can be applied to this phase.

### 7.2.2 Malicious embedded firmware

Hardware that has any intelligence requires firmware, so the hardware knows how to operate. Firmware typically sits in non-volatile memory and is not authenticated prior to execution making it vulnerable to attack through alterations. This characteristic of firmware makes firmware susceptible to attack at many stages in the SCLC. This subclause deals with malicious firmware during the design and creation of firmware by the original designer. It is important to note that manufacturers of ICT products can take the firmware from the hardware manufacturer and change it for their unique need or ignore it all together and replace it with their own firmware or that of another third party.

Due to the fluidity of firmware from the original product designer throughout the supply chain, it is important for firmware to be maintained and tracked with good source code management tools and version control processes. Firmware not only changes within the supply chain, prior to provisioning, but it is not uncommon for it to change throughout phase 5 and even into phase 6. Firmware changes in the utilization phase typically occur to address performance and security updates in the hardware that were not discovered in validation.

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In design, all firmware can include a process for adding a digital signature to the firmware prior to distribution so the ICT process can verify the signature and only load the firmware if the signature is valid. The signature ensures the firmware has not been tampered with in phase 2. Combining this process with the security design life cycle practices can improve confidence in the validity of the firmware.

### 7.2.3 Malicious hardware

Malicious hardware (HW) can be introduced by an internal or external source adding additional circuitry into a design that performs a function other than what was specified in the product requirements. Best practices to mitigate the implementation of malicious HW are the implementation of peer code reviews and the utilization of code scanners. Additionally, characterizing the normal behaviour of the HW enables the implementation of test cases that test for abnormal behaviours.

Malicious HW results in additional circuitry added to the design. The hardware performs all the functionality to meet the design requirements but has additional circuitry that can activate only after a specific condition exists (number of executions, amount of time since power on, etc.). It is almost statistically impossible to exhaustively test with every possible input vector. The types of hardware trojans are broad, but it is technically possible to send data back to an unauthorized party. Another hardware trojan can invoke a destructive action or prevent any action during the operation of the product.

### 7.2.4 Malicious software (driver)

Software drivers and firmware typically come from the hardware supplier, but there are instances where these are provided by a third party. This can be done when a single software driver is controlling components from multiple hardware manufacturers, and it requires the integration of multiple sets of software into a single signed software module. This software is susceptible to the same design threats for software implemented internally, like the insertion of hidden functionality. To mitigate this threat, when selecting suppliers it is important to consider the SDL and supply chain controls followed by the supplier. Additionally, validation results can be made available as part of the product delivery to ensure that there can be independent verification of code scans results and test results and to ensure no abnormal behaviour. Requiring only signed software as a standard practice enables software traceability directly back to the signing organization and possible verification that no manipulation has occurred. Performing static code scans of each version of software provided will give an additional internally verifiable result to the state of the software provided.

Malicious software can also occur from software tampering. Some common types of software tampering mechanisms are described in Annex F.

### 7.2.5 Counterfeit

Counterfeit components can appear to operate within the requirements established by stakeholders, but can suffer from substandard materials and insufficient quality controls and validation, leading to unpredictable life. This can lead to higher failure rates, inoperability within the required environment (heat, moisture, vibration, etc.) and the inability to hold the product manufacturer accountable.

One best practice which can be implemented in the supply chain is to buy only from distributors that are authorized (by the manufacturer of the component). Another best practice is to perform routine audits of the suppliers on their security practices to prevent counterfeit parts from entering their supply chain. Audits can include observation of supply chain practices, destructive tests on components and verification of validation results.


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# 8 Phase 3: Source and manufacture

## 8.1 General

This is the phase where the materials and components are manufactured into ICT products. There are many threats in the production process that can impact the performance of the product or expose intellectual property for theft. Like other phases, phase 3 requires an implementation of good practices in information technology processes as well as supply chain processes, to ensure consistency.

## 8.2 Source

Source is the acquisition of goods or services from a third party, which contributes to the ICT component or product. This is the phase to prepare necessary materials and tools for the production. The materials include not only raw materials, components, software, but also services like storage, building and validation. Companies typically implement a comprehensive sourcing strategy that includes establishing security criteria in addition to their corporate responsibility and quality criteria to be used in the selection of the supplier. The parties responsible for supply chain assurance and information security define the criteria. This means the criteria can be used to align supplier expectations with the goals to prevent threat vectors occurring at earlier points of the life cycle. Additionally, controls through audits or quantifiable assurance (documented proof) can be added as part of the criteria for supplier selection and ongoing monitoring.

## 8.3 Manufacture

Manufacture is the phase to integrate final products from the materials prepared in the previous source phase. During the integration and at the completion of the manufacturing, a series of tests and evaluation can be applied. In some cases, middle products can be transferred from one facility to the other. In that case, phase 4 protection is applied. At the end of the manufacturing, it is important to configure the products as “end of manufacturing” state, which disables all manufacturing interfaces such as debug and test ports.

## 8.4 Summary of production threats and controls

### 8.4.1 Attack on production tools, data exchange tools and/or network

The same security threats and prevention mechanisms described in 6.2.1 can be applied to this phase.

In ICT product manufacturing, most fabrication equipment is very sophisticated, and the equipment is serviced by the equipment manufacturer’s technicians. There are two methods of maintenance. The first method is through the network, in which case access controls are expected to be very tight and typically are opened and closed by the builder rather than leaving a business-to-business connection open for someone to take advantage of the open connection to affect the performance of the equipment. Alternatively, technicians can come into the factory to service equipment. In this case, the technician can be supervised or electronically monitored while in the factory to protect assets from theft, manipulation, or insertion of foreign materials into the build process.

### 8.4.2 Unauthorized disclosure

Most of the design files used in the creation of components are only shared under the strictest of non-disclosure agreements (NDAs). However, violations of these NDAs, either intentional or unintentional, are not always reported by the violating party. This expands the insider threat potential beyond just the manufacturer to include every supplier or vendor that is given sensitive information about the manufacturer’s products. Methods to minimize accidental or purposeful disclosure include:

— applying digital rights management (DRM) to design files with policy settings that restrict viewing files unless specifically granted by the owner of the file, thereby limiting physical access to the manufacturing floor;

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— training technicians and engineers on how to properly handle information and designs they readily use to perform their jobs.

### 8.4.3 Reverse engineering / theft of design

Any design that can be created can also be reverse engineered. Even if an attacker cannot gain direct access to the design files, extraction of the synthesized files (processed designs) can allow for possible reverse engineering of critical design secrets. This can include cryptographic keys stored within the products. Detection of a stolen design can be enabled by obfuscating the cryptographic key by dispersing it throughout the circuitry (vs. having fuses in sequential placement) or having the algorithm generate a unique hash based upon the unique chip design and including this as part of the key.

### 8.4.4 Improper system settings

Final validation of finished products can include steps to ensure proper system state before it leaves the manufacturing facility. System settings that are open in manufacturing to enable the correct configuration of an ICT product are expected to be locked prior to leaving the end of the manufacturing line.

### 8.4.5 Design alteration

Alteration of the design can occur during a number of stages by various actors. It is possible for a supplier to suggest a seemingly innocuous change that actually provides the ability to induce an undefined state of execution in the system. An integrator can also make a covert change to the design files provided as part of an integration effort, and a substitute component can be swapped out due to supply shortages or in an effort to save costs.

To mitigate impact by suppliers, a contractual agreement can be implemented to ensure that every change to a material goes through a formal engineering change order (ECO) process and all parties can weigh in on the change and determine the impact before the change is implemented. All material testing performed by the supplier is expected to be made available for inspection if the designer sees anomalies in product quality or performance.

To mitigate against changes between the designer/OEM and the manufacturer, contract wording is expected to disallow alteration and define a process for the manufacturer to engage the designer/OEM for temporary modification of design due to unforeseen conditions, such as natural disasters impacting design supply of approved components. In addition, the designer/OEM is expected to require as-built BOM information to be provided for each of the ICT products built so that it can be compared against the engineering and manufacturing BOMs to ensure they match. The ability to perform teardown verification of every material in the product is a means to sample check conformance to the design.

### 8.4.6 Insertion of malicious and/or counterfeit components

A malicious component is a device that has been made to look like and function identically to a valid component but has some level of additional functionality that performs a malicious action when triggered. A malicious component can also be a lower value or functionality component that has been intentionally used to replace higher value or functionality component, after all validation testing has occurred. One example is that attackers can seek to replace original memory components with slower memory, tarnishing the name of the suppliers (given that faster memory costs more than slower memory, but both perform the same functions).

A counterfeit component is a device that is expected to function like the legitimate device but can lack in quality, performance of rigor of validation. These devices can be easily distinguishable when powered on due to power draw or throughput deviations from the norm, yet they are easily inserted during later stages of the phase 4 when only visual validation is performed.

To mitigate these risks, the manufacturer's sourcing processes are expected to be verified to ensure sourcing from only authorized distributors with rigorous controls in place. Additionally, the manufacturers' internal processes are expected to place controls on the movement of materials.


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