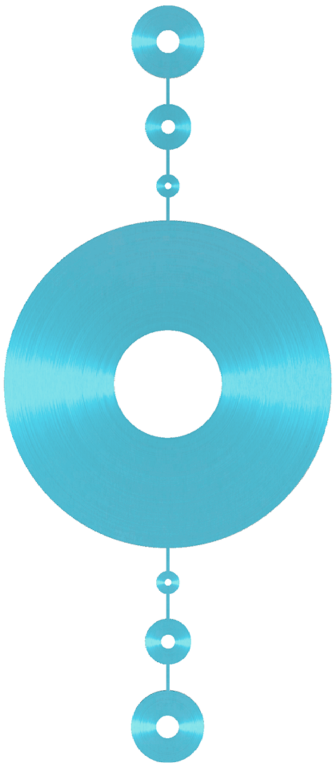
IAR Embedded Workbench®

Safety Guide



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Contents

Using a build toolchain in functional safety projects

This guide contains information that is relevant when you use IAR Embedded Workbench® for creating high-integrity software that has functional-safety requirements. The guide is a complement to the IAR Embedded Workbench user guides.

1 Introduction

The purpose of this guide is to highlight issues that you should consider when you use the build toolchain in IAR Embedded Workbench® for projects with functional-safety requirements or more general high-integrity requirements. The focus of this guide will be on different topics covered by the international standards IEC 61508 edition 2.0 and ISO 26262. However, the guide is applicable to any development project where functional safety or high integrity is part of the requirements.

For each topic, IAR Systems provides various notes of advice that are relevant for the build toolchain (such advice is marked with **Advice**). This guide encourages you to consider the relevance of each listed advice and discuss the implications related to your application with project stakeholders, and when applicable, the appointed functional safety assessor.

Note: Some notes of advice apply only to a specific microcontroller or to a specific feature set which might not be available in the toolchain you are using. If so, this will be mentioned.

It should be noted that the demands of the mentioned standards are very seldom absolute requirements; almost any practice, decision, or deviation can be justified as long as there is valid and sufficient rationale for it. Further, the decisions and activities proposed by the standards differ depending on the selected integrity level for the project.

The guide assumes a basic understanding of the requirements and proposed best practices brought forward by a relevant safety standard with regards to implementation languages, implementation and test practices, and build toolchains.

References to sections and paragraphs of IEC 61508 will be given for further background information.

The information in this guide is valid for the following IAR Embedded Workbench products and associated instruction sets and CPU cores:

IAR Embedded Workbench for *	**Version**	**CPU cores**
ARM	6.40.1 and later	ARM instruction sets ARMv4, ARMv5, ARMv6, ARMv6-m, ARMv7, and ARMv7-m
AVR	6.11 and later	tinyAVR, megaAVR, and AVR XMEGA
AVR32	4.10 and later	AVR UC3
S08	1.20 and later	S08
HCS12	3.20 and later	HC12, S12
CF	1.23 and later	V1 and V2
CR16C	3.10 and later	CR16C
RL78	1.20 and later	RL78
RX	2.40 and later	RX
RH850	1.10 and later	RH850
M16C	3.50 and later	M16C/1X–3X, 5X–6X, R8C
78K	4.71 and later	78K0, 78K0S, and 78K0R
H8	2.20 and later	H8S and H8/300H
M32C	2.30 and later	M16C/8X and M32C
R32C	1.31 and later	R32C
V850	3.81 and later	V850, V850E, V850ES, V850E2, V850E2S, V85E2M
SH	2.20 and later	SH2A
STM8	1.30 and later	STM8
430	4.50 and later	MSP430 and MSP430X
8051	8.10 and later	8051/8052 and compatible

Table 1: IAR Embedded Workbench products

*** The information in this guide might be useful for IAR Embedded Workbench products also for other CPU cores than listed in this table.**

Note: In this guide, *IAR C/C++ Development Guide* refers to the *IAR C/C++ Compiler Reference Guide* and the *IAR Linker and Library Tools Reference Guide* if your product package includes the XLINK Linker, or the *IAR C/C++ Development Guide* if your product package includes the ILINK Linker.

1.1 THE SCOPE OF TOOL USAGE AND ASSUMPTIONS OF USE

The IAR Embedded Workbench is a toolchain for writing, translating, debugging, and deploying applications written in C/C++ or assembler language where the target architecture typically is a microcontroller.

The build chain consists of the following components with their respective use cases:

- The compiler: used for translating C and C++ programs to object code. The compiler can produce diagnostic messages and list files to help tracking down any programming errors. Optionally, the compiler also checks conformance to MISRA C:2004 or MISRA C:1998 rules and can for some target architectures produce meta information used by the linker to compute worst-case stack usage.
- The assembler: used for translating assembler language input to object code. The assembler produces diagnostic messages and list files to help tracking down any programming errors.
- The linker: the linker accepts files in object format and resolves outstanding references to function calls, variables, and assembler level jumps. As output, the linker can produce a fully resolved binary image that can be downloaded to the target system, a fully resolved binary image that contains debug information which can be used in a debugger to debug the application, or it can produce library files that can be linked to other object files to produce a fully resolved binary image.
- Optionally, the IAR Embedded Workbench product you are using might allow the enabling of the add-on tools C-STAT for static analysis and C-RUN for runtime error checking. These add-on tools are not strictly part of the build chain, although they can be used as an integral part of your quality assurance.

2 System and environment considerations

This section covers topics that you should consider very early in your project setup.

2.1 LANGUAGE STANDARDS COMPLIANCE

The build toolchain that is part of IAR Embedded Workbench supports C and C++, including some dialects. For information about the supported languages and their dialects, see the IAR language overview in the IAR C/C++ Development Guide.

This guide will focus on advice applicable for the C language. All advice is generally applicable also for C++, but if you have chosen C++ for your project it is especially important to consider the advice given in the safety standards that govern your project on how object-oriented features can be used safely. See for example Annex G of IEC61508-7.

Before you start a project with functional safety requirements, consider these issues:

- If you have decided to use C/C++, safety standards generally advise you to use plain C with a suitable language subset or C++ with a suitable language subset. The build toolchain supports both C99 (Standard C) and C89. See table *C.1 in IEC61508-7 and section 7.4.4 in IEC61508-3* for advice on language selection.

  Advice 2.1-1: Make an informed decision on what language, language dialect, and subset you will use.

  Advice 2.1-2: Consider available tools that enforce the use of suitable language subsets, for example MISRA C rule checkers.

- If you have decided to use C, safety standards generally advise you to use Standard C without any extensions. However, it can be very useful from an implementation and code quality perspective to use various language extensions, for example hardware-specific keywords or intrinsic functions.

  Advice 2.1-3: Consider isolating the use of language extensions to specific modules to maximize the portability of the code base and simplify the use of compiler-independent code analysis tools. Such isolation also facilitates proper testing of the code that depends on the language extensions.

- The C Standard library provided with IAR Embedded Workbench contains functionality mandated by the C Standard. The library is delivered by a third-party vendor and adapted by IAR Systems to suit typical resource-constrained microcontrollers. Different standards for software development with functional safety requirements put different constraints on the use of such pre-existing code and functionality. For certain functionality, such as I/O and threading, the library depends on a low-level interface that you must implement yourself. For more information about the DLIB runtime environment, see the *IAR C/C++ Development Guide*. For more information about using DLIB in a functional safety project, see *The C/C++ standard libraries*, page 28.

  Advice 2.1-4: Consider how pre-existing code should be treated and tested.

  Advice 2.1-5: Consider how to implement and test the parts of the low-level interface that are needed by your application.

- The libraries supplied also contain low-level code to handle system startup and exit, as well as runtime routines needed by compiled code, for example floating-point arithmetic. The IAR Systems implementation adheres to a freestanding implementation of Standard C/C++, which among other things means that the code for system startup and exit for your application is under your control.

Advice 2.1-6: Consider not using the default code for system startup and exit, but instead using your own versions to fully control the behavior of your application.

Advice 2.1-7: If you decide to use your own versions of startup and exit code, consider how this code should be handled and tested. For more information, read about system startup and termination in the IAR C/C++ Development Guide.

Advice 2.1-8: Read about implementation-defined behavior for Standard C in the *IAR C/C++ Development Guide*.

2.2 IAR LANGUAGE EXTENSIONS

The IAR compiler supports many different language extensions that can be divided in two categories:

- Extensions for embedded system programming
- Relaxations to Standard C.

The first set of extensions covers additions to the language that makes it easier to deal with the specific hardware that you are using. This category includes extensions like type and object attributes for memory placement and memory area selection, alignment control, interrupt routine definitions, relaxations for permitted types in `enum` and bitfield definitions, intrinsic functions to use special features of the target CPU, etc.

The second category consists of relaxations of some rules in Standard C that are very restrictive. These relaxations are similar to how many other C compilers behave by default. Extensions include for example, conversions between `void` pointers and other pointer types in some situations, assignment and pointer difference between types that are interchangeable but not identical, single value initializations of arrays, structs, etc.

Safety standards generally advise that no language extensions, implementation-defined behavior, or undefined behavior should be relied upon. However, it might be difficult to develop high-quality embedded systems without relying on tool-specific functionality, for example to access memory-mapped peripheral devices and to create interrupt handlers. Another example is accessing special features of the CPU that do not map naturally to the C/C++ language without using special compiler-provided *intrinsic* functions.

Advice 2.2-1: For development of software with functional safety requirements, there can be a trade-off between using a well-tested language extension and implementing the same functionality by other means. Discuss with your assessor and other stake holders how to proceed when you can choose between using a language extension or implementing similar functionality in your own source code. In your decision, consider factors like maintainability, portability, usability, and readability.

Advice 2.2-2: Read about using C and C++ in the IAR C/C++ Development Guide, for an overview of the different levels of available language extensions.

Advice 2.2-3: In your coding standard, include advice about how to use language extensions.

Advice 2.2-4: Partition source files and header files to isolate the use of language extensions as much as possible. This might include creating a formal hardware abstraction layer.

Advice 2.2-5: The build chain does not by default enable generation of *remarks*, the least severe type of diagnostic messages. Enabling remarks can give you additional hints on language constructs that are non-standard, non-portable, or might produce unintended results.

It can sometimes be necessary to implement a piece of functionality directly in assembler language. You can find a description of the accepted assembler syntax for your product in the *IAR Assembler Reference Guide*.

Advice 2.2-6: Consider that assembler syntax is often very vendor-specific, which means that assembler code written for a specific toolchain is seldom directly portable to another toolchain for the same target architecture.

Advice 2.2-7: Consider carefully if there are alternatives to using assembler language, due to the lack of portability and the risk of introducing errors that are hard to find in the interaction between the high-level C/C++ source code and the assembler code. Read about mixing C and assembler in the *IAR C/C++ Development Guide*.

2.3 MISRA C STANDARDS AND THE MISRA C CHECKER

Safety standards generally require you to adopt a coding standard to deal with hazardous constructs in the programming language you select. For C, it is recommended that your coding standard incorporates the MISRA C rules or another set of rules with similar intent.

Note: The current revision of the MISRA guidelines is MISRA C:2012, which is currently not supported by the built-in MISRA C checker in the compiler. However, the C-STAT static analysis add-on tool supports MISRA C:2012, as well as MISRA C:2004 and MISRA C++:2008.

Advice 2.3-1: If you decide on any of the MISRA C standards, the MISRA C guidelines recommend using at least one MISRA C checker to get the best possible quality of analysis.

Advice 2.3-2: If you are using the full version of IAR Embedded Workbench, you can set up its MISRA C checker for the previous MISRA C:2004 or MISRA C:1998 standards to be part of the build process. In this case, you should also consider using another MISRA C checker. Because the built-in MISRA C checker in IAR

Embedded Workbench is based on the same technology as the IAR C/C++ Compiler and has the same view of the source code as the compiler, it is important to rule out common modes of error by using more than one checker.

Advice 2.3-3: Get a copy of the relevant MISRA C standard to review the rationale for each rule and aim to adhere to all MISRA C rules in your project and make deviations a rare exception.

Advice 2.3-4: If you decide to ignore certain rules globally, consider configuring the MISRA checker to ignore those rules to minimize irrelevant messages. For example, both C-STAT and the built-in MISRA checkers can be configured to ignore specific rules globally and for individual files.

2.4 HAZARD AND OPERABILITY ANALYSIS

Safety standards generally require you to perform a *hazard and operability analysis* (HAZOP analysis) of potential tool failures. See section *7.4.4.5 in IEC61508-3 and section C.6.2 in IEC61508-7*.

In the context of the build toolchain, a HAZOP analysis can be interpreted as an analysis of possible failure modes.

Advice 2.4-1a: Consider the following possible failures (the different types of diagnostic messages) when setting up the tools environment and when planning the test and validation activities:

- Remarks

  Using C/C++ in a non-standard-compliant fashion will generate a remark (minor remarks are only produced when the `--strict` compiler option is used). Other sources for remarks are source constructs which potentially might cause problems in the application. To enable remarks, use the `--remarks` compiler option.
- Warning messages

  Warning messages are in general an indication that the toolchain has identified potentially erroneous or ambiguous behavior in your source code, in the compile stage or the link process.

  Advice 2.4-1: Strive for clean builds with no warning messages.

  Advice 2.4-2: Consider having guidelines on when and how it is acceptable to ignore tool warnings.

  Advice 2.4-3: Consider enabling the proper build options to treat all warnings as errors, at least for release builds and integration builds.

  Advice 2.4-4: If a particular warning must be ignored to accomplish the desired effect, this warning should be documented and signed off.

Note that the absence of warnings does not indicate that your code is free from potential erroneous or ambiguous constructs. IEC 61508 recommends the use of a well-defined language subset, like the MISRA C:2012 or the MISRA C:2004 rules, to avoid such constructs.

- Error messages

  The toolchain will not produce code for modules that produce error messages. Thus, error messages are benign from a functional safety perspective as they cannot be ignored.

- Option settings not treated correctly.

  Advice 2.4-5: Consider verifying that no options set explicitly in the IAR Embedded Workbench IDE are ignored by the build tool. To verify this, you should make sure that each option you have set is listed as part of the active command line in the build tool list files.

  Advice 2.4-6: Examine any implicitly set options to make sure that their effects are in line with the project goals. For example, when some optimization settings are enabled, a set of dependent functionality will be assumed. That functionality can be turned off by explicit options.

  For example, for the optimization level High, a set of transformations will be implicitly enabled and must be explicitly disabled by a specific option. See for example the `--no_cse` option for an example of such an option.

  Advice 2.4-7: In the IAR Embedded Workbench IDE, the **Options** dialog box verifies that incompatible options cannot be active at the same time. For options that you specify directly on the command line, the toolchain will warn about conflicting settings.

  However, for some options it is impossible for the tool to know whether dependent options are allowed or not. For example, if you select the CPU core explicitly instead of specifying a specific device, there is a risk that you enable core-specific features that are not available on the device you are using. Review your option settings to make sure the correct functionality is achieved.

- Internal errors

  Internal errors are indications from the toolchain that it has detected an internal inconsistency that prevents the tool from generating correct output. An internal error can be the result of unexpected erroneous input to the tool or a malfunctioning of the tool in response to correctly formed input.

Advice 2.4-8: If you receive an internal error from the build toolchain, you should report it as a bug to your support contact at IAR Systems or your reseller. Inspect the input that caused the internal error to determine if the input is supposed to be valid according to language standards and other constraining factors, or if the input is erroneous. For more information about technical support services, see the Server Center section at www.iar.com.

- Silent errors

  A silent error is a tool error that is not reported by any kind of diagnostic message and thus has the potential to silently produce malfunctioning code. This type of error is of course the most problematic kind of tool error and as such should be given some extra thought in the test and validation planning.

  Advice 2.4-9: Consider these strategies that can be employed to prevent and catch this kind of issue:

  - Regularly access updated information from the tool vendor about newly found and fixed issues in the toolchain. This information is available in release notes for new versions. For very demanding projects, you can consider approaching your tool vendor for a special support agreement to get the most up-to-date information on known issues.
  - Create different build configurations that differ in, for example, compiler optimization settings, linker configuration, and debugger setup. Each build configuration is then subjected to the same set of tests as the build configuration used for release builds and any discrepancies are analyzed. A side effect of this kind of testing is that erroneous source code that happens to work with one set of build options can be found. As an example, consider a piece of code that does not use the `volatile` keyword correctly; this code might execute the tests correctly for low compiler optimization levels, but sometimes break on higher optimization levels.

    Advice 2.4-10: As a minimum, consider a matrix of configurations exercising combinations of the following properties:

    - Maximum and minimum optimization levels.
    - For a CPU architecture that can accept different instruction sets, consider adding at least one test configuration for the instruction set that will not be used for release builds.
    - If the standard C library is used, configure the runtime library in different ways to validate that application behavior is correct for the chosen configurations.

  - If your application uses floating-point arithmetic and the chosen CPU contains an FPU unit, consider disabling the FPU support in one test configuration.

- ❍ Different test coverage metrics collected on unit tests and integration tests help direct test efforts to achieve the needed confidence level for correct functionality. The primary reason to employ coverage-directed testing is to validate correct behavior of the implemented functionality, but as a side effect also potential tool errors will be efficiently discovered.

  Note that some safety standards require 100% code coverage for the selected coverage metric. See for example *IEC61508-3, table B.2* and *IEC61508-7, part C.5.8*.

- ❍ Strive for code that does not depend on any implementation-defined behavior or any undefined behavior as defined by the language standard. Further, strive for code that is clean with respect to the MISRA C rule set or the selected coding standard.

2.5 DEVICE-SPECIFIC SUPPORT FILES

The product package contains support files for various devices. Depending on the exact product you are using, the number of supported devices can range from less than a hundred up to several thousand.

Files needed to support a specific target device are usually made up of these types:

- I/O definition header file. Such a file defines mnemonic names for peripheral units and memory mapped peripheral device registers, so that they can be accessed from the code with names resembling the names in the user documentation.
- Device definition file for the C-SPY debugger. Such a file defines, for example, device-specific memory regions to give the debugger the possibility to check memory accesses and other functionality.
- Linker configuration file. Such a file instructs the linker on how to place code and data segments for a specific device or device family.
- Flash loader support. Device-specific or device family-specific debugger plugin to download code to flash.
- C-SPY macro file. A general macro file that is sometimes used for setting up specific functionality of the debugger or device prior to execution of code.

All such support files are to be considered as convenience files. The toolchain can be used without support files and you can always supply the needed information or work around the need for it. The build toolchain does not depend on the support files and you are in fact encouraged to create, for example, your own linker configuration file.

Note: Often, these files are supplied by the device manufacturer and the amount of validation of the files is minimal. However, errors in support files are easily detected, since they usually make the hardware behave incorrectly, or make it not work at all.

Advice 2.5-1: Make sure you have a clear picture of the support file dependencies for your project. Discuss with project stake holders and, if applicable, your assessor on how to treat these files and whether special measures are needed to test their functionality, besides integration testing.

Advice 2.5-2: If you are planning on using a device that is so new that it is not covered by any support files in your product package, you can often retrieve the needed support files from a newer, certified or non-certified, version of IAR Embedded Workbench for your target CPU or in certain cases directly from your device manufacturer. However, for reasons of reliability and accumulated confidence from use, you should possibly consider using a well-known device that is already on the market.

2.6 COMPATIBILITY BETWEEN DIFFERENT VERSIONS OF THE SAME TOOLCHAIN

A major product update, for example from version 5 to version 6, of an IAR toolchain is most probably not backward compatible. This means that all source code of an application must be recompiled or reassembled using the new version.

All IAR Systems tools display their version number as part of the sign-on message or, for example, in list files when executed from the command line.

Advice 2.6-1: Before you update an IAR toolchain, make sure that any third-party libraries that are used are available in a version that is compatible with the new IAR toolchain version.

A minor update, for example from version 6.1 to version 6.2, of an IAR toolchain is most probably backward compatible. However, problems found and corrected in supported public Application Binary Interfaces (ABI) can make the toolchain backward incompatible.

Advice 2.6-2: Read the release notes for the IAR toolchain to see whether there are any backward incompatibilities before updating to the new version.

Note: Any updates to a certified version of IAR Embedded Workbench are always backward compatible.

2.7 COMPATIBILITY WITH OTHER TOOLCHAINS

An IAR toolchain is as a rule not fully compatible with other vendors' toolchains for the same microcontroller. Depending on which object format and which application binary interfaces your product uses, the IAR toolchain can be interoperable with toochains from other vendors. Normally, this means that source code written for the IAR toolchain:

- Can use global variables and functions in the linked-in code from other toolchains
- Might fail to link, or link but fail at runtime if the code from another toolchain uses C library functionality or if that code needs compiler-intrinsic support.

Advice 2.7-1: If you are using an IAR toolchain other than IAR Embedded Workbench for ARM, read the IAR C/C++ Development Guide for any information about compatibility with toolchains from other vendors.

Advice 2.7-2: If you are using a supported standardized ABI, for example the ARM AEABI or the RX C ABI, read about ABI compliance in the IAR C/C++ Development Guide for information about whether code produced by third-party tools can be linked. If that is the case, you can also find information about how to do it and with what limitations.

Basically, an ABI defines:

- The C library interface
- The compiler intrinsic library (support functions needed for the compiler)
- The C++ runtime interface (support for exceptions, rtti, new/delete, etc, but not for the C++ library interface itself).

The ABI makes it possible to use any third-party code—if compiled in ABI mode—in an application, and it will be treated as any other code in the application.

Advice 2.7-3: If you import third-party code, make sure that it is translated with the correct ABI mode enabled. Also make sure that the complete application is translated with the ABI mode enabled.

Note: The ABI information applies only to product packages that include the ILINK Linker.

2.8 GENERAL GUIDELINES ON MCU SELF-CHECK STRATEGIES

Safety standards advise or mandate the use of various self-checking strategies for runtime integrity of the hardware. For example, consider the requirements stated by the IEC 60730 standard for white goods appliances. For some classes of appliances, this standard poses detailed requirements on the use of memory checking strategies, stack pointer checking, and the use of a watchdog timer for various purposes. These tests are focused on detecting hardware errors. However, similar strategies can be used for testing various aspects of the software integrity. Most CPU vendors that aim for this appliance area have created libraries to help their customers with this testing. This means that even if you are not working under IEC 60730 requirements you can take advantage of existing libraries to enhance the testability of your software by using or modifying selected tests.

Advice 2.8-1: Familiarize yourself with the self-check requirements in the IEC 60730 or other application standard, even if you have no specific self-check requirements for your project.

Advice 2.8-2: Review and use vendor libraries to implement the selected tests. making sure that you have a clear understanding of what a selected library tests for and what it does not test for. If applicable, discuss with your functional-safety assessor how to best use library functionality.

Advice 2.8-3: Follow the advice on stack depth checking in this guide.

Advice 2.8-4: Implement and run appropriate tests also for projects that do not explicitly mandate their use.

3 Installation, commissioning, operation, and maintenance

For information about how to install, invoke, use, and maintain IAR Embedded Workbench and its build toolchain, see the installation and licensing documentation.

For a project with functional safety requirements, consider the following issues:

Advice 3-1: A new toolchain or an updated version of a toolchain should never be installed on top of an existing toolchain, unless there are very specific reasons to do so.

Advice 3-2: Never install IAR Embedded Workbench so that it shares the `common` directory with another IAR Embedded Workbench unless there are very specific reasons for doing so. Doing so means that the two different versions share the common IDE and debugger components. Installing IAR Embedded Workbench so that it shares the `common` directory with another version means that the existing installation will potentially get updated with newer (or older) common components from another product.

However, if two installations of IAR Embedded Workbench *do* share the `common` directory, there are mechanisms to ensure module consistency. By means of runtime model attributes, the linker ensures that modules that are linked into an application are compatible.

Note: The IAR Embedded Workbench installation wizard proposes an installation path. If the new installation is incompatible with a previous installation, the proposed path is not the same as for the previous installation.

Note: If your project involves more than one CPU and the CPUs use different IAR toolchains, it can be useful to let the toolchains share the `common` directory. But in that case, consider implementing a versioning policy to avoid accidental updates of common components.

Advice 3-3: If you create automated builds that are not based on the IAR Embedded Workbench *workspace* and *project* files, consider making all references to the build tools absolute and not dependent on, for example, environment-provided path variables or similar.

Advice 3-4: Consider archiving the entire build environment as a snapshot before you update any of the tools in the toolchain. The archiving can be done in any way you like as long as it is practically possible to recreate and use a previous build environment at a later stage.

Advice 3-5: The typical workflow and build process in IAR Embedded Workbench is similar to corresponding process in other integrated development environments. However, it is likely that setup, configuration, customization, and adoption of the toolchain have different degrees of freedom compared to other toolchains. The workflow and build process is described in detail in the *IAR C/C++ Development Guide* and in the *Getting Started with IAR Embedded Workbench®* guide. Read and familiarize yourself with this information.

You are encouraged to keep up to date with any newly identified issues in the toolchain. If you have a valid support and update agreement for functional safety you will periodically and automatically receive information from IAR Systems on issues that are relevant for development under functional safety requirements. This information should be reviewed and assessed for potential impact on your source code.

If you have identified an error or problematic condition in the toolchain, you are encouraged to report this to IAR Systems. The information you provide will be processed at IAR Systems. You will receive feedback on whether the issue is in fact a bug or not, and in the case of a confirmed bug, you will also receive potential workarounds and a tracking ID for the issue that maps to information in release notes and other communication. If the issue has consequences for functional safety development, the issue will be included in the periodic information from IAR Systems together with the ID.

See the Service Center section on `www.iar.com` for more information on how to submit bug reports.

4 Setting up the build environment

This section covers topics related to designing your build environment.

4.1 DEBUG MODE, RELEASE MODE, AND BUILD CONFIGURATIONS

IAR Embedded Workbench supports the concept of *build configurations* whereby you can easily specify different ways to build and debug an application. One build configuration can differ from another build configuration by option settings, the set of defined preprocessor symbols, and the set of files included in the build. When you create a project, IAR Embedded Workbench automatically creates two build configurations—*Debug* and *Release*. There are several practical reasons for creating different build configurations. For more information about how to create and use build configurations and the differences between the two default configurations, see the *IAR Embedded Workbench® IDE User Guide.*

Note: For IAR Systems compilers, adding debug information does not have any impact on performance, nor on the size of the executable image. No actual instructions or data storage are introduced when debug information is added to the link image. The only information that is added is meta information used by the debugger to cross-reference instructions, stack, registers, and labels to the source code.

Advice 4.1-1: Consider at least the following build configuration scenarios to be part of your test and validation cycle:

- ❍ Build configurations with different optimization goals

  Using different optimization goals can help you track errors caused by source code that depends on undefined behavior or implementation-defined behavior according to the language standard. This strategy can also help in identifying performance issues with the code.

- ❍ Clean release build configuration

  In an early stage in your project cycle, you should define and create a build configuration that is used for release builds. This build configuration should be set up to be as close as possible to the needs of the final production environment, including optimization levels and production-ready output file format if applicable. This build configuration should be used as the basis for all testing throughout the project. Unless there are specific reasons otherwise, the output file of this build configuration is what should be delivered to external stakeholders outside the software development team.

  The build configuration should never be changed unless production needs dictate a change. If you need a build configuration based on the release configuration with changes for debugging purposes, the changed configuration should be cloned from the release configuration.

  Note that if you enable debug support in the compiler, meta information will be added to the object file. The debugger can use this meta information to display high-level information when running the application. This information does not have any impact on how the application behaves at runtime. However, when you set options for the runtime library and the C/C++ standard library, and if you choose to enable debug support for certain low-level I/O functionality that enables functionality like file operations on the host computer, etc, such debug support will have an impact on the performance and responsiveness of your application.

Advice 4.1-2: Dynamic runtime analysis tools like C-RUN can be an excellent help in pinpointing potential error sources and directing test efforts. Add one or more build configurations to set up the build environment for the analysis tool. For more information about C-RUN, see *Add-on analysis tools*, page 23.

Note: Analysis tools that operate on a running application typically instrument the code being tested by adding code to detect interesting situations and keep track of statistics. This impacts the performance characteristics of the code. Therefore, if tests are run on instrumented code, you should still make sure that the non-instrumented application passes all relevant tests.

4.2 BUILD OPTIONS

Advice 4.2-1: When you set up a new build project and workspace, make sure you only include relevant settings for the particular build configuration. Consider reviewing these examples:

- ❍ Preprocessor symbols used for directing conditional compilations should be reviewed to verify, for example, that there are no irrelevant preprocessor defines specified for the release build configuration.
- ❍ The setup of your CPU, data and code models (if applicable in the toolchain you are using), etc. The settings you make should neither be too permissive or too restrictive.
- ❍ For certain devices, you have a choice to use different memory byte orders (little- and big-endian). Make sure you have selected the correct byte order options for your target architecture and that the selection also matches that of any third-party code you use in your project.
- ❍ Linker and standard library settings should be reviewed to verify that C standard library I/O is handled the proper way.
- ❍ Library settings should be reviewed to verify, for example that the library supports the application's needs, or that it does not contain superfluous features, etc.
- ❍ Settings for the programming language should be reviewed to verify, for example the sign of the `char` type, the level of ANSI compliance, enabled extensions like intrinsic functions, etc.
- ❍ If your project needs different build options for different source files, consider collecting files with similar settings in a dedicated source code group in your

IAR Embedded Workbench project, to avoid accidentally changing or leaving settings in place for files where the project-global settings are overridden.

- If you are using the add-on tool C-RUN to analyze the behavior of your code at runtime, certain compiler and linker options must be set. These options should typically not be set for final production code. For more information, see *Advice 4.1-2* and *Add-on analysis tools*, page 23.

Advice 4.2-2: Read about compiler and linker options in the *IAR C/C++ Development Guide*. Read about assembler options in the *IAR Assembler Reference Guide*.

4.3 STACK DEPTH CONSIDERATIONS

Advice 4.3-1: Consider these issues:

- Keep stack allocation to a minimum.
- Allocate resources statically in an early stage of your project. In that way, it is possible to know already at link time exactly how much memory these resources will claim. However, for small data items with small scope and transient lifetime, referencing these static objects can potentially consume more registers and increase stack depth. Examples of such objects are loop counters and similar objects used for short-lived or temporary data.
- Pay attention to worst-case length of function call chains and recursion chains, and remember that interrupts increase stack usage.
- Consider implementing your own procedure, possibly tool-assisted, to assess stack depth for your application.

Advice 4.3-2: Consider writing a *magic number* or pattern at startup to each RAM memory location that is not used for stack, dynamic heap memory, or instructions. This pattern can be checked periodically during runtime by a dedicated stack check routine. Depending on the exact requirement specified by the safety standards, this check can either be enabled only for testing purposes or be a part of the final release build. A careful selection of the fill pattern can also assist you in identifying stack overflows and buffer overruns manually when you view the memory section in a debugger memory window.

4.3.1 Stack usage analysis

Depending on which product you are using, IAR Embedded Workbench incorporates stack usage analysis that can assist you in computing the worst case stack depth for your application code. The advantages of using the stack usage analysis integrated with the compiler and linker toolchain is that the stack analysis operates on the same information about stack usage and layout as the compiler and linker do. For more information about stack usage analysis, see the IAR C/C++ Development Guide.

Advice 4.3.1-1: Consider using stack usage analysis if it is available in your product.

4.3.2 Tracking stack usage using the debugger

The **Stack** window in the C-SPY debugger can optionally track stack usage. For more information, see the *C-SPY® Debugging Guide*.

When your application is first loaded, and upon each reset, the memory for the stack area is filled with the dedicated byte value `0xCD` before the application starts executing. Whenever execution stops, the stack memory is searched from the end of the stack until a byte with a value different from `0xCD` is found, which is assumed to be how far the stack has been used. Although this is a reasonably reliable way to track stack usage, there is no guarantee that a stack overflow is detected. For example, a stack *can* grow incorrectly outside its bounds, and even modify memory outside the stack area, without actually modifying any of the bytes near the stack range. Likewise, your application might modify memory within the stack area by mistake.

Advice 4.3.2-1: Consider using the stack usage tracking functionality in C-SPY.

Advice 4.3.2-2: If you use a product that supports the add-on tool C-RUN for runtime error checking, consider setting up one or more test configurations that use C-RUN to detect various errors, including conversion errors and out-of-bounds issues.

4.4 LINKER CONFIGURATION

Safety standards generally advise that applications operating under functional safety requirements should not use dynamically allocated objects on the heap or the stack. See for example table *B.2 in IEC61508-3*. Note that the standard makes a distinction between *objects* and *variables*.

Advice 4.4-1: Familiarize yourself with the configuration possibilities of the linker.

Advice 4.4-2: If you must use dynamically allocated objects on the heap or the stack, consider this:

- Familiarize yourself with heap setup also for projects that do not use dynamic memory allocation so that heap memory is not accidentally allocated (thus impacting on available memory space).
- Avoid placing a large amount of data on the stack. Plan for this already during the architecture and implementation phases.

Advice 4.4-3: Make sure the linker generates map files and that you review the map file generated for your release build configuration regularly.

For information about how to set up the linker configuration file, including information about how to set up and allocate memory for the runtime stack and for the dynamic memory allocation on the heap, see the IAR C/C++ Development Guide.

4.4.1 Heap memory allocation

C/C++ constructs that use heap memory are:

- The C heap interface: `malloc`, `calloc`, `realloc`, and `free`.
- Variable length arrays (VLA). The actual storage for such arrays are allocated on the heap.
- Certain C library functionality, such as:
  - File I/O
  - Locale
  - `printf` and `scanf` for `wchar_t` formatters
- The C++ heap interface: `new` and `delete`
- C++ exceptions
- The C++ standard template library (STL)
- Most of the C++ library.

If the heap is used dynamically, there is a risk that it will be increasingly fragmented. This means that it will be more and more difficult to allocate a large amount of heap memory. Sooner or later, the application will run out of heap memory even though the amount of free bytes on the heap is sufficient.

Advice 4.4.1-1: To reduce the effects of this problem, consider these strategies:

- Use a tool that checks that any used heap memory is freed when it is no longer needed.
- Use the heap only locally, for example by making a function allocate the heap memory it needs and when finished, make the function free the same amount of memory.
- Allocate the heap memory at the startup of the application and never free the heap.

Advice 4.4.1-2: To make sure that the heap is not used from the application by accident, change the setup in the linker configuration so that no RAM is allocated for the heap. Any use of the heap will then return or throw an `Out of memory` error.

4.5 ADD-ON ANALYSIS TOOLS

Some IAR Embedded Workbench products have add-on tools for static and dynamic/runtime error checking.

- C-STAT, a tool for static analysis of C/C++ source code, supports MISRA C:2012, MISRA C:2004, and MISRA C++:2008 as well as numerous coding rules from CWE and CERT.

- C-RUN, a tool for runtime error checking, can detect various runtime errors, like conversion errors, shift errors, pointer out-of-bounds issues etc. C-RUN is currently only available for IAR Embedded Workbench for ARM.

For more information about C-STAT and C-RUN, see the *C-STAT® Static Analysis Guide* and the *C-SPY® Debugging Guide for ARM*, respectively.

Advice 4.5-1: If you decide to use one or both of these tools, you should consider the following:

- ❍ C-RUN and C-STAT are add-on tools and are not certified against any functional safety standard. This does not imply that the tools cannot be used in projects with safety requirements, on the contrary, they can help you find programming errors and issues at an early stage. Discuss with your assessor how to incorporate C-RUN and C-STAT in your development cycle.
- ❍ C-RUN and C-STAT are designed to be used in the daily development workflow and are fully integrated into the IAR Embedded Workbench IDE. This means that the tools accept exactly the same language dialects as the build chain; thus no configuration of language compliance is needed. Likewise, no configuration for adaptation to the build environment is needed.
- ❍ Messages reported by the analysis tools should be reviewed to determine whether they are sensible. However, note that errors reported by C-RUN are reported from running code, which means that the code under test is likely to contain code constructs that break one or more language rules.

5 Implementation and coding considerations

This section covers topics related to the implementation and coding of your application.

5.1 OPTIMIZATION MODES

5.1.1 Optimization modes overview

The compiler performs many transformations on your application to generate the best possible code. Examples of such transformations are storing values in registers instead of in memory, removing superfluous code, reordering computations in a more efficient order, and replacing arithmetic operations by more efficient operations.

Note: The more optimization that is applied to the source code, the less the resulting machine code's structure will resemble the structure of the original source code. This means that at high optimization levels, it is difficult to map the produced machine code to the corresponding source code statements and it is difficult to preserve the values of variables during debugging.

Advice 5.1.1-1: Sometimes it is not possible to use any compiler optimizations at all, either for code or for parts of the code, because of detailed requirements on the traceability of functional safety requirements down to object code. Discuss the feasibility of using optimizations with your functional-safety assessor and other project stake holders.

5.1.2 Facilitating compiler transformations

You should be aware of the fact that some source code constructs can inhibit compiler optimizations. Such constructs can also often be overly complex, difficult to understand and maintain, and seldom give any clear benefits in terms of code size or execution speed.

Advice 5.1.2-1: Review the texts about compiler transformations in the IAR C/C++ Development Guide and in the *Getting Started Guide.*

Advice 5.1.2-2: Group together functions that have timing constraints into separate modules and use speed optimizations. Use size optimizations on the rest of the application.

5.2 INTEGRAL TYPE SELECTION

In some situations, the rules for integer types and their conversion lead to possibly confusing behavior. Several operators in the C Standard convert operands from one type to another automatically. This includes the rules about integer promotion, implicit conversion, and common arithmetic conversions. For more information, see chapter 6.3 Conversions in the C99 standard.

Advice 5.2-1: Things to look out for are assignments or conditionals (test expressions) involving types with different size, and logical operations, especially bit negation.

Advice 5.2-2: Use a well-defined language subset, like the MISRA C:2012 rules or the MISRA C:2004 rules, to avoid such constructs.

For information about integer types, arithmetic, and how to avoid common mistakes, see the IAR C/C++ Development Guide.

5.3 FLOATING-POINT ARITHMETIC

The build toolchain complies with the IEEE 754 standard for representing floating-point numbers. Support for subnormal numbers and exception flags varies with the CPU and the availability of an FPU unit.

Finite representation of arbitrary decimal numbers will generally lead to rounding and truncation errors.

Advice 5.3-1: If floating-point calculations have any relevance for the safety functions of your application, consider analyzing the validity and precision of the calculations.

Note that some safety standards have additional rules and guidelines related to floating-point arithmetic. See table *A.9, IEC61508-3*.

For more information about floating-point representation, see the IAR C/C++ Development Guide.

5.4 FUNCTIONS

The C standard supports two different styles for function declarations—the Kernighan & Ritchie style and the prototyped style. The K&R style is only supported for compatibility reasons.

Advice 5.4-1: Always use prototype style when declaring and defining functions. The compiler does not check parameter types for correctness when a function declared using K&R style is called.

Advice 5.4-2: Always declare public functions in a header file that is visible from all source files that define or use the function. This ensures that the declaration is always synchronized with the definition, and that all callers call the function with type-correct parameters.

Advice 5.4-3: Use the **Require prototypes** compiler option (`--require_prototypes`) to make the compiler check that no K&R style function declarations/definitions are used, and that a prototype declaration is present before the definition of each public function.

5.5 GLOBAL SYMBOLS

The safest way to use global symbols, such as functions and variables, is to make sure that the symbol is known to the compiler before the symbol is used. You achieve this by declaring the symbol in a header file and including that header file in any source file that uses that symbol.

Advice 5.5-1: There should be only one declaration of a symbol in the whole source code, placed in a header file. Any module that uses the symbol includes that header file.

Advice 5.5-2: All symbols should have distinct names.

5.6 CONST AND VOLATILE

The semantics of the `volatile` type qualifier—as specified in the C standard—prohibits the compiler from removing accesses to a `volatile` object and reordering accesses to `volatile` objects. A `volatile` object is always placed in read-write memory even if the object is `const` declared.

Advice 5.6-1: Make sure you understand all the implications of the `volatile` keyword:

- ❍ Read about `volatile` in the IAR C/C++ Development Guide for information about how the specific IAR toolchain you are using treats `volatile` objects.
- ❍ Declaring an object `volatile` informs the compiler that it must not optimize away accesses and order of accesses to the object.
- ❍ Declaring an object `volatile` is *not* a guarantee that the object will be thread-safe.
- ❍ Declaring an object `volatile` is *not* a guarantee that accesses to the object will be atomic. It can be true for certain operations for certain object types and sizes, but if atomicity is a required property for object access it must be ensured by other means.
- ❍ Declaring an object `volatile` without guarding object accesses from different execution contexts with some locking mechanism, might make your timing-dependent source code work in one specific compiler version using specific optimization settings. Changing the compiler version, the optimization settings, or making minor changes to the source code might lead to erroneous behavior, unless simultaneous access to the object from different execution contexts is properly guarded against.

For more information about using `volatile`, see the IAR C/C++ Development Guide.

The `const` type qualifier only means that write accesses to the object are forbidden. Therefore, non-constant objects and constant objects will be placed in memory that is addressed in exactly the same way.

Advice 5.6-2: Read about `const` in the IAR C/C++ Development Guide for information about how the specific IAR toolchain you are using treats `const` objects.

Note: In some IAR toolchains, `const` objects are placed in RAM. In this case, the toolchain provides, for example, a specific memory attribute that can be used for placing such objects in ROM.

5.7 POINTERS

Data pointers to objects with different type qualifiers (`const` and `volatile`) point to the same memory and use the same access method. If the CPU supports different areas of data memory, the IAR toolchain will probably support one data pointer type for each different data memory. One of the data pointer types will be used by default.

Advice 5.7-1: If the compiler you are using supports several data pointer types, make sure to use the data model that is most suitable for your application. Read about data models in the IAR C/C++ Development Guide.

Function pointers are in general not compatible with data pointers. Saving function pointers in `void *` types might not work. If the CPU supports several areas of code memory, the IAR toolchain will probably support one function pointer type for each code memory area. One of the function pointer types will be used by default.

Advice 5.7-2: If the compiler you are using supports several function pointers, make sure to use the code model that is most suitable for your application. Read about code models in the IAR C/C++ Development Guide.

6 The C/C++ standard libraries

This section discusses the use of the C/C++ standard library in projects with functional safety requirements. The C/C++ standard libraries contain functionality that is not part of the core language but still standardized. This includes, for example, I/O functionality, string manipulation, and mathematical functions in the C library, and the parameterized algorithmic functions in the C++ library. The following discussion is restricted to the C standard library, but the same general principles hold also for the C++ standard library. For a brief discussion of the C standard library in a safety context, see *Language standards compliance*, page 7.

Advice 6.0-1: See the IAR C/C++ Development Guide for detailed information on the C/C++ standard library in IAR Embedded Workbench. For information about the standard library functions, see the online help system.

6.1 THE C STANDARD LIBRARY

In a functional safety context, the C standard library is most often considered as pre-existing software; see for example section *7.4 in IEC61508-3* and section *C.2.10 in IEC61508-7*. This means that you must take special measures when using functionality provided by the library. In general, you must evaluate all of the available information on design, verification, testing and usage of the pre-existing software element. As a result of the evaluation, measures can be devised to handle specific issues. In the following text, a number of issues are listed that can help you make informed decisions about library usage.

6.1.1 Design

- The C standard library provided with IAR Embedded Workbench is licensed from Dinkumware; the world-leading supplier of standard-conformant C/C++ standard libraries. Their libraries are used by many tool vendors, including other compiler and build chain vendors, and organizations that prefer to use a well-known library implementation. Dinkumware actively participates in the standardization work for the C/C++ standard libraries and also actively works together with test suite providers and parser companies to make sure that their interpretation of the standard is correct and in harmony with the rest of the industry.

- The C standard library is designed to be fully compliant with the ISO/IEC 9899:1999 standard, also known as C99. The library is then customized by IAR Systems to be as efficient as possible on different target hardware platforms. This also includes the possibility to select downscaled support for I/O, for example.
- The library is delivered as a set of pre-built object libraries. Each such specific library is built to match, for example, a chosen support level for I/O, a specific calling convention, a specific instruction subset etc., and combinations of such features and choices. For example, for ARM-based microcontrollers this might include the possibility to call the library from both a 16-bit instruction set and a 32-bit instruction set.
- For a majority of IAR Embedded Workbench product flavors, the full library source code is included in the product package, which makes code review of the full library or selected parts possible.
- Furthermore, the book *The C Standard Library* (Prentice Hall, 1992) by P. J. Plauger, the founder of Dinkumware, describes the design of the library.

Advice 6.1.1-1: Assess the need for, and potential gain from, using library functionality. Consider incorporating a restricted set of allowed functions into the coding standard and strictly forbidding the use of other functions.

Advice 6.1.1-2: Assess the available design information and identify possible gaps in the information with respect to the information required in your project. Note that implementation complexity varies much between different functions in the library. Perform code reviews on the parts of the library that you would benefit from using and cross-refer to the standard for the C standard library.

Advice 6.1.1-3: Note that the library is C99-compliant also when the compiler is instructed to be C89-compliant. This means that some functions will have a slightly different or extended functionality compared to the C89 standard.

Advice 6.1.1-4: Note that some low-level library functions like `memcpy` might under certain circumstances be treated as compiler intrinsic functions, thus making them part of the compiler. See section 2.2 in this guide for a discussion of language extension usage. See the IAR C/C++ Development Guide for more information on when and how that can happen.

6.1.2 Verification and test

The library is thoroughly tested by Dinkumware before delivery to their customers. Dinkumware uses a combination of in-house conformance tests and stress tests, as well as third-party test suites from Perennial and Plum-Hall. The test suites are cross-referred to the standard to make sure that all functionality is verified and validated. Basically the same tests, including some Dinkumware-internal tests are then replicated by IAR Systems on the modified library, plus additional stress tests and regression tests. This includes real-world applications making use of the library. See the *Dinkumware statement* for a statement from Dinkumware on design, test and verification.

Advice 6.1.2-1: Assess and review publicly available information from Dinkumware, Perennial, and Plum-Hall on their test suites.

6.1.3 Usage

Advice 6.1.3-1: If your assessment of the library indicates that you can use certain parts of the library, consider the following items:

- Defensive programming: In a library context this includes techniques for sanity checking and invariant checking of data that passes the API boundary between the application and the library.
- Unit tests: By implementing project-specific unit tests of selected library functionality, project-specific confidence can be increased. If full library source code is available, code reviews can be used to design in-depth tests that incorporate knowledge of implementation choices.
- Overriding existing functionality: It might in certain circumstances be beneficial to replace a certain part of the library with a targeted implementation, for example to restrict the input domain of some specific function or similar. Note that this requires a thorough understanding of the inner workings of the library.
- Re-building the full library: It is possible to configure and re-build the library to better suit the intended usage. Note that this requires a thorough understanding of the inner workings of the library and is only recommended for handling very special requirements.

Advice 6.1.3-2: Make sure that you understand the implications of library thread safety and library usage and configuration. For more information, read about managing a multithreaded environment in the IAR C/C++ Development Guide.