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Guidance for the Use of Reverse-Engineering Techniques

Revision 1 to EPRI TR-107372

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Guidance for the Use of Reverse-Engineering Techniques

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ABSTRACT

As the marketplace and manufacturing methods evolve, aging equipment and associated spare parts become increasingly difficult to obtain and may eventually become obsolete. In some cases, reverse-engineering techniques can be used to facilitate replacement of existing items while minimizing the need for extensive design changes.

However, risk is inherent when applying reverse-engineering techniques as examination of an existing specimen alone may not be sufficient to ensure that the reverse-engineered design includes provisions that address factors such as how the device functions with interfacing equipment or conditions in the installed environment. Therefore, it is important to understand the design functions of the item to which reverse-engineering techniques are being applied.

In addition, reverse-engineered items are subject to the same types of design control considerations as other replacement items. Control of design should be documented in an appropriate evaluation.

This report was prepared to assist Electric Power Research Institute (EPRI) members and their suppliers in the effective application of the reverse-engineering techniques and associated design controls necessary to accept the use of designs established through reverse-engineering techniques for use in nuclear power applications. Effective use of reverse-engineering techniques and associated design controls prevent introduction of unintended design changes and associated unevaluated failure modes and mechanisms.

Keywords

Configuration management
Duplication
Design control
Obsolescence
Replicate
Reverse engineering

EXECUTIVE SUMMARY

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PRIMARY AUDIENCE: Individuals such as procurement engineers, design engineers, and technicians at licensee and supplier facilities who are involved in the use of reverse-engineering techniques and associated engineering evaluation processes such as equivalency evaluation and design change.

SECONDARY AUDIENCE: Individuals such as quality assurance professionals involved in reverse-engineering projects and equipment reliability professionals involved in managing obsolescence.

KEY RESEARCH QUESTION

What logical process can be followed to successfully apply reverse-engineering techniques in commercial nuclear power facilities? As equipment ages, obtaining the spare and replacement items needed to support maintenance becomes increasingly challenging. Reverse-engineering techniques are employed in military and other critical application industries and have proven to be an effective method for obtaining replacements for obsolete items. Although a significant amount of design input can be obtained through examination of a specimen, application of reverse-engineering techniques for safety-related items includes developing an understanding of the design functions of the item, considering how the item interfaces with other equipment, and knowing how the item behaves in its operating environment. In addition, existing design control processes should be used to document acceptability of items obtained via reverse-engineering techniques.

RESEARCH OVERVIEW

A technical advisory committee consisting of Electric Power Research Institute (EPRI) members, suppliers with experience in reverse engineering, and regulatory representatives was assembled. The committee reviewed recent regulatory documents associated with reverse engineering as well as EPRI guidance on reverse engineering developed in the late 1990s and identified areas in which to update and expand the guidance. A detailed process was developed to address use of reverse-engineering techniques, review of designs informed via use of reverse-engineering techniques, and selection of an appropriate design control process. The process developed can be applied in any country's regulatory framework.

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KEY FINDINGS

- Risk is inherent when reverse-engineering techniques are applied.
- The process described in Section 4 for application of reverse-engineering techniques addresses regulatory concerns associated with understanding design functions, interface requirements, and design control.
- Effective communication between the licensee and external entities performing reverse-engineering techniques is critical to ensure that appropriate design functions, interface requirements, *in situ* conditions, and other considerations inform application of reverse-engineering techniques.
- Replacement items obtained through using reverse-engineering techniques are subject to the same design control measures as other replacement items. Do not assume that a replacement item design recovered using reverse-engineering techniques is identical or equivalent to the original item.

WHY THIS MATTERS

Application of the process included in this report provides added assurance that reverse-engineered items can perform their design functions in their operating environment. Appendices A, B, and C include tools that can be used to ensure that vital information is communicated between the licensee and the entity applying reverse-engineering techniques.

HOW TO APPLY RESULTS

Individuals involved in performing reverse engineering of items should become familiar with Sections 1 through 5 of this report and apply the process detailed in Section 4. Individuals involved in establishing equivalency or suitability of design for reverse-engineered items should carefully review Sections 4.4 through 4.8 and Section 4.12 of this report.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Reverse engineering and other emerging issues related to procurement and procurement engineering for nuclear power plants are regularly discussed at EPRI Joint Utility Task Group Procurement Forums.
- This report was developed based on application of reverse-engineering techniques for nuclear safety-related items. However, many aspects of the guidance can also be applied to non-safety-related equipment.
- This report may be of interest to individuals involved in procurement and maintenance of non-nuclear generating facilities. Although reverse-engineered equipment used in non-nuclear generation is not subject to nuclear regulations, failure modes potentially introduced by inadequate reverse-engineering methodology or engineering evaluation of reverse-engineered items could impact reliability and operability of plant equipment.
- This product might be of interest to the generation sector or any organization responsible for maintaining large capital assets.

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LEXICON AND ACRONYMS

Lexicon

1E	A U.S. safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal or that are otherwise essential in preventing significant release of radioactive material to the environment. Source: IEEE-308 [39]
administrative change	An inconsequential change to an alternate item without physical changes (no change to form, fit, or function) of the specified part, for example, only a manufacturer's part number changes. An administrative change may require a change in plant documents, but it will not require a physical change to the plant or additional engineering/design analyses. Source: EPRI 1008254 Revision 2 [40]
bounded technical requirements	A subset of technical requirements that is established through engineering activities that translate the values chosen as reference bounds for the design of controlling parameters, for example, the design bases as defined in 10CFR50.2 [41] into specific requirements. Source: EPRI 3002002982 [12]
design	Technical and management processes that commence with the identification of design input and lead to and include the issuance of design output documents. Source: ANSI N45.2.11-1974 [6]
design bases	Design bases means that information which identifies the specific functions to be performed by a structure, system, or component of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. These values may be (1) restraints derived from generally accepted "state of the art" practices for achieving functional goals, or (2) requirements derived from analysis (based on calculation and/or experiments) of the effects of a postulated accident for which a structure, system, or component must meet its functional goals. Source: 10CFR50.2 [41]

design change	A change to those bounding technical requirements that (1) ensure performance of design basis functions or (2) ensure compliance with the plant licensing basis. Source: EPRI 1008254 [40]
design characteristics	Sometimes referred to as “critical characteristics” for design, those properties or attributes that are essential for the item’s form, fit, and functional performance. Critical characteristics for design are the identifiable and/or measurable attributes of a replacement item that provide assurance that the replacement item will perform its design function. Source: EPRI 3002002982 [12]
design input	Design input includes those criteria, parameters, bases, or other design information upon which the final design is based. This can include technical information, design bases, performance criteria, regulatory requirements, codes, standards, analysis, and calculations. Sources: NUREG 1913 [42], ANSI N45.2.11-1974 [6]
design equivalent change or equivalent change	A change that does not result in an adverse change to those bounded technical requirements that (1) ensure performance of design basis functions or (2) ensure compliance with the plant licensing bases of either the item(s) or applicable interfaces, including the applicable codes and standards to which the licensee is committed. Source: EPRI 1008254 [40]
design output	Design output includes documents such as drawings, specifications, and other documents that define the technical requirements of structures, systems, and components. Sources: NUREG 1913 [42], ANSI N45.2.11-1974 [6]
engineering judgment	A determination based on prior examples, experience, or observation that has not been subjected to rigorous engineering validation. Source: NUREG 1913 [42] A process of logical reasoning performed by a qualified individual that leads from stated premises to a conclusion. This process should be supported by sufficient documentation to permit verification by a qualified individual. Source: NRC inspection procedure IP 43004 [43]
equivalency evaluation	A technical evaluation performed to confirm that an alternate replacement item (not identical to the original) will satisfactorily perform its design function. This term is synonymous with “item equivalency evaluation.” Sources: EPRI 1008256 [44], NISP-EN-02, Revision 0 [45]

licensee	An entity to which the applicable regulatory agency has granted a license to construct or operate a nuclear facility or to receive, possess, use, transfer, or dispose of source material, byproduct material, or special nuclear material. Adapted from U.S. NRC online glossary https://www.nrc.gov/reading-rm/basic-ref/glossary/licensee.html
obsolete/obsolescence	The condition of being out of date due to development of better or more economical products, methods, processes, machinery, or facilities, resulting in a loss of value or competitive advantage. Items may be available in the market but are no longer needed in a specific application. The condition of no longer being available in the market due to lack of manufacturer support. Items that are needed in a specific application but are no longer available or supported by the original manufacturer and are difficult to otherwise procure and qualify. [48]
Operations-critical document	Operations-critical documents are the subset of controlled documents affected by modification that require updating prior to equipment turnover to the plant Operations department. These documents would be immediately required to align and place the system in operation, remove the system from service, respond to trouble/troubleshooting with the modified system/component, or to respond to an accident in which the system is needed. Examples might include operating procedures, maintenance procedures, one-line or logic diagrams, operating curves, calculations that specify or support operating procedures, station software, and emergency or security procedures.
patent	A right granted to inventors by the government to exclude others from making, using, or selling their invention to the public for a period of 20 years. Whoever invents any new process, item, or composition matter may obtain a patent. An issued patent contains the specifications and drawings submitted with the patent application. The patent right is not the patent right of the inventor to make, use, or sell the invention, but a grant to exclude others from doing so. All the inventor obtains is the right to sue. Source: MIL-HDBK-115C [3]
Q-list	A document identifying those structures, systems, or components for a nuclear power plant that are safety related. Source: EPRI 1008256 [44]

reverse engineering (RE)	The process of developing technical information sufficient to obtain a replacement for an item by physically examining, measuring, testing existing items, reviewing technical data, or performing engineering analysis.
technical requirements	Parameters that define the function or performance of a given system, structure, or component in a particular application/end use or group of applications/end uses. Sources: EPRI TR-1008254 [40], EPRI 3002002289 [47]

Acronyms and Abbreviations

1E	safety-related (pertaining to electrical equipment)
3D	three-dimensional
AC	alternating current
ADAMS	NRC Agency-wide Documents Access and Management System
A/E	architect/engineer
ABMA	American Bearing Manufacturers Association (formerly Anti-Friction Bearing Manufacturers Association)
AISC	American Institute of Steel Construction
amp	ampere
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATP	acceptance test procedure
BOM	bill of material
CAD/CAM	computer-aided design/computer-aided manufacturing
CENELEC	European Committee for Electrotechnical Standardization
CFR	Code of Federal Regulations

CMM	coordinate measuring machines
CMTR	certified material test report
C	Celsius
CSSC	critical structures, systems, and components
CT	computed tomography
DC	direct current
DIN	German Institute for Standardization (Deutsches Institut für Normung)
DMLS	direct metal laser sintering
EGM	electric governor magnetic
EMI	electromagnetic interference
EPRI	Electric Power Research Institute
EPROM	erasable programmable read-only memory
EQ	equipment qualification
F	Fahrenheit
FDM	fused deposition modeling
FMEA	failure modes and effects analysis
FSAR	final safety analysis report
FTIR	Fourier transform infrared
HPCI	high-pressure coolant injection
I&C	instrumentation and controls
IE	Inspection & Enforcement (NRC)
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Standards Organization

LCD	liquid crystal diode
LED	light-emitting diode
MEL	master equipment list
MIL	military
MTBF	mean time between failures
MTBR	mean time between repairs
NDE	nondestructive examination
NEMA	National Electrical Manufacturers Association
NIST	National Institute for Standards and Technology
NSSS	nuclear steam system supplier
NRC	U.S. Nuclear Regulatory Commission
OAC	Operations activity checklist
OCD	Operations-critical documents
OE	operating experience
OEM	original equipment manufacturer
OES	original equipment supplier
PCB	printed circuit board
PTH	plated through hole
PO	purchase order
QA	quality assurance
QC	quality control
RAD	radiation absorbed dose
RADS TID	rads total ionizing dose

RCIC	reactor core isolation cooling
RE	reverse engineering
RFI	radio frequency interference
RGSC	ramp generator and signal converter
RRS	required response spectra
RTD	resistance temperature detector
SSC	structures, systems, and components
UNS	unified numbering system
UL	Underwriters Laboratories
U.S.	United States
VDC	voltage direct current
VIB	U.S. Nuclear Regulatory Commission Vendor Inspection Branch
XRF	X-ray fluorescence

CONTENTS

ABSTRACT ..... **V**

EXECUTIVE SUMMARY ..... **VII**

1 **BACKGROUND AND INTRODUCTION** **1-1**

1.1 Purpose of This Report 1-1

1.2 Objective of Reverse-Engineering Techniques 1-1

1.3 Design Control 1-1

1.4 Regulatory Perspective 1-2

1.5 Background 1-2

1.6 Applications for Reverse-Engineering Techniques 1-3

2 **PRELIMINARY CONSIDERATIONS** **2-1**

2.1 Legal Considerations 2-1

2.2 Licensee and Supplier Responsibilities 2-1

2.3 Coordination Between the Licensee and the Supplier 2-2

2.4 Complexity and Risk Considerations 2-3

2.4.1 Inherent Risk 2-3

2.4.2 Risk Versus Cost and Schedule 2-3

2.4.3 Risk of Unsuccessful Outcome 2-4

2.4.4 Factors and Resulting Risk 2-4

2.5 Reverse-Engineering Team 2-6

3 **USE OF EXTERNAL RESOURCES AND THE IMPORTANCE OF EFFECTIVE COMMUNICATION** **3-1**

3.1 Use of External Resources 3-1

3.1 Initial Information Communicated Between the Licensee and Supplier 3-2

3.1.1 Interface Plan 3-2

3.1.2 Documenting the Initial Exchange of Information 3-3

3.2 On-Going Communication of Information 3-3
3.3 Communication of Reverse-Engineering Output 3-3

4 **DETAILED PROCESS FOR USING REVERSE-ENGINEERING TECHNIQUES 4-1**
4.1 Identify the Objectives, Applications, and Functions 4-4
4.2 Identify the Original Item's Design Characteristics 4-5
4.3 Establish/Vet the Replacement Item's Design 4-6
4.4 Determine the Design Control Activity 4-7
4.5 Procurement Evaluation 4-10
4.6 Item Equivalency Evaluation 4-10
4.7 Design Engineering Review 4-11
4.8 Design Equivalent Change or Design Change 4-11
4.9 Unable to Proceed 4-12
Steps 4.2.1–4.2.7 Sub-Process to Identify the Original Item's Design Characteristics 4-13
Steps 4.3.1–4.3.11 Sub-Process to Establish/Vet Replacement Item Design 4-26
Steps 4.4.1–4.4.8 Sub-Process to Determine Design Control Activity 4-38

5 **SPECIAL CONSIDERATIONS ASSOCIATED WITH THE USE OF REVERSE-ENGINEERING TECHNIQUES 5-1**
5.1 Below the Level of Detail 5-1
5.2 Sources of Original Design Information 5-2

6 **INSPECTION, MEASUREMENT, AND TESTING OF MECHANICAL DEVICES 6-1**
6.1 Special Considerations for Application of Reverse-Engineering Techniques to Mechanical Items 6-1
6.1.1 Configuration Using Inspection 6-1
6.1.2 Material Identification 6-1
6.1.3 Material Condition Determination 6-1
6.1.4 Coatings/Hard-Facing Identification Using Inspection 6-3
6.2 Practical Considerations for Mechanical Items 6-3

7 **INSPECTION, MEASUREMENT, AND TESTING OF ELECTRICAL AND ELECTRONIC DEVICES 7-1**
7.1 Special Considerations for Application of Reverse-Engineering Techniques to Electrical and Electronic Items 7-1
7.2 Specialized Electrical/Electronic Reverse-Engineering Tools 7-1
7.3 Electrical/Electronic Analysis 7-1

7.4 Practical Considerations for Electrical and Electronic Items 7-3
7.5 Examples of Electronic Reference Standards 7-3

8 **ESTABLISHING TOLERANCES 8-1**
8.1 General Guidance 8-1
8.2 Basis for Establishing Tolerances 8-2
8.3 Item Interfaces 8-2
8.4 Consult a Manufacturer 8-2
8.5 Manufacturing Processes 8-3
8.6 Surface Finish 8-3
8.7 Scientific Methods of Establishing Tolerances 8-7
8.7.1 Tolerance Analysis 8-8
8.7.2 Tolerance Allocation 8-10
8.8 Tolerance Stack-Up 8-10
8.9 Special Considerations for Electrical/Electronic Tolerances 8-10
8.10 Standards and Other References for Establishing Tolerances 8-11

9 **ADVANCED REVERSE-ENGINEERING TECHNOLOGIES 9-1**

10 **TABLETOP EXAMPLES 10-1**
10.1 Resistance Temperature Detector 10-1
10.2 Complex Pressure-Retaining Mechanical Component 10-4
10.3 Valve Stem 10-8
10.4 Pipe Plug 10-11
10.5 Control Relay 10-14
10.6 Fire Protection Panel 10-18
10.7 Ramp Generator and Signal Converter 10-23
10.8 Power Supply 10-29
Description 10-29

11 **REFERENCES 11-1**

A **FORM FOR INITIATING APPLICATION OF REVERSE-ENGINEERING TECHNIQUES A-1**
A.1 Purpose A-1
A.2 Instructions for Completing the Form A-1
Section A, Contact Information A-1

Section B, Item Identification A-1
Section C, Item Information A-2
Section D, Available Information A-3
Section E, Supplier Information A-3

***B* FORM FOR TRACKING AND DOCUMENTING INFORMATION RECOVERED DURING APPLICATION OF REVERSE-ENGINEERING TECHNIQUES B-1**

B.1 Purpose B-1
B.2 Instructions for Completing the Form B-1
Section A, Contact Information B-1

***C* EXAMPLE OF SUMMARY REPORT FORMAT C-1**

LIST OF FIGURES

Figure 2-1 Relative Impact of Complexity and Risk Factors 2-6
Figure 4-1 Process Map Key 4-2
Figure 4-2 Process for the Application of Reverse-Engineering Techniques 4-3
Figure 4-3 Identify the Original Item's Design Characteristics 4-13
Figure 4-4 Establish/Vet Replacement Item Design, page 1 of 2 4-26
Figure 4-5 Establish/Vet Replacement Item Design, page 2 of 2 4-27
Figure 4-6 Determine the Design Control Activity, page 1 of 2 4-38
Figure 4-7 Determine the Design Control Activity, page 2 of 2 4-39
Figure 5-1 Design Information Typically Available to Plant, Design, and Supplier Organizations 5-2
Figure 8-1 Relative Cost of Production Versus Tolerances 8-1
Figure 8-2 Relationship of Manufacturing Processes and Tolerances 8-3
Figure 8-3 Representative Surface Finish of Common Components 8-5
Figure 8-4 Relationship of Surface Finish to Manufacturing Processes (ANSI B46.1) 8-6
Figure 8-5 Relative Cost Versus Surface Finish 8-7
Figure 9-1 Preparing to Scan a Part Using a FARO Three-Dimensional Scanner at Duke Energy's Central Receiving and Dedication Facility 9-2
Figure 9-2 Dynamic Scanning of a Specimen Item Using FARO Edge with Laser Line Probe HD to Capture the Data Set for the Development of a Point Cloud 9-3
Figure 9-3 After 3D Scanning Individual Piece Parts into Geomagic Design X, Individual 3D Models Were Developed Using SOLIDWORKS and Assembled to Test the Fit-Up. 9-3
Figure 9-4 A 3D Model Developed in SOLIDWORKS from a Point Cloud Processed in Geomagic Design X. The 3D Models Will Be Used to Create Two-Dimensional (2D) Drawings for Fabrication Purposes. 9-4
Figure 9-5 A Printed Circuit Board and the Image Captured Using ScanCad International ScanFAB at NextEra Energy, Incorporated 9-6
Figure 9-6 An Automated Circuit Card Prober Used by NextEra Energy, Incorporated 9-7
Figure 9-7 A Technician at NextEra Energy, Incorporated, Analyzing a Circuit Card Used in Wind Turbines 9-8
Figure 10-1 RTD and Thermowell Assembly (Photo courtesy of United Controls International) 10-1
Figure 10-2 Valve Stem (Photo courtesy of Curtiss-Wright Nuclear Division) 10-9
Figure 10-3 Typical Pipe Plug (Photo courtesy of Curtiss-Wright Nuclear Division) 10-12
Figure 10-4 Control Relay (Photo courtesy of United Controls International) 10-14

Figure 10-5 Acceptance Testing of Fire Protection Panel and Associated Detectors (Photo courtesy of Dynamic Solutions USA, Incorporated) 10-18
Figure 10-6 Woodward RGSC 9903-087 – Front (Photo courtesy of Paragon Energy Solutions, LLC)..... 10-23
Figure 10-7 Woodward RGSC 9903-087 – Back (Photo courtesy of Paragon Energy Solutions, LLC)..... 10-23
Figure 10-8 Reverse-Engineered First Article – Front (Photo courtesy of Paragon Energy Solutions, LLC)..... 10-23
Figure 10-9 Reverse-Engineered First Article – Back (Photo courtesy of Paragon Energy Solutions, LLC)..... 10-23
Figure 10-10 Replacement Power Supply Designed Using Reverse-Engineering Techniques (Photo courtesy of AZZ Nuclear Engineered Solutions)..... 10-30

LIST OF TABLES

Table 1-1 Activities Associated with the Term *Reverse Engineering* 1-5
Table 2-1 Customer and Supplier Responsibilities for Typical Scenarios 2-2
Table 2-2 Factors and Resulting Risk 2-5
Table 4-1 Process Flow Charts for the Use of Reverse-Engineering Techniques 4-1
Table 4-2 Typical of Evaluations Associated with Design Control and Use of Reverse-Engineering Techniques 4-9
Table 6-1 Tests Useful in Material Identification 6-2
Table 6-2 Tests Useful in Determining Material condition 6-2
Table 8-1 Standard Tolerances and Grades 8-4
Table 8-2 References for Establishing Tolerances 8-11
Table 9-1 Examples of Items that Can Be Scanned Using Advanced Technologies 9-2

1
BACKGROUND AND INTRODUCTION

1.1 Purpose of This Report

The purpose of this report is to provide guidance regarding the application of reverse-engineering techniques to support replacement items for commercial nuclear facilities. This report supersedes EPRI TR-107372, *Guidelines for Reverse Engineering at Nuclear Power Plants* [1]. The objective of the report is to present a process that:

- Can be used to approach common applications of reverse-engineering techniques
- Includes licensee measures for design control
- Incorporates lessons learned from the application of reverse-engineering techniques
- Includes perspective that can be applied by suppliers specializing in application of reverse-engineering techniques

This report was developed based on the application of reverse-engineering techniques for safety-related items. However, many aspects of the guidance can also be applied to non-safety-related equipment.

1.2 Objective of Reverse-Engineering Techniques

Reverse-engineering techniques are applied in situations where complete design information is not available. The objective of reverse engineering is to enable manufacturing or otherwise acquiring a replacement item that will be capable of performing the original intended design functions. Reverse-engineering techniques involve examining an existing specimen as well as review and analysis of information available about the item's design and its design functions.

1.3 Design Control

Design control is a primary consideration when reverse-engineering techniques are used to support replacement of items for a commercial nuclear power facility. Quality management programs for nuclear facilities require control of design. Application of reverse-engineering techniques alone is not a substitute for design control activities. Therefore, it is necessary to document control of design using established processes such as equivalency evaluation, design equivalent change, and design change.

1.4 Regulatory Perspective

In July of 2016, the U.S. Nuclear Regulatory Commission (NRC) issued Information Notice 2016-09: Recent Issues Identified When Using Reverse Engineering Techniques in the Procurement of Safety-Related Components [2]. The information notice summarizes issues and concerns associated with the use of reverse-engineering techniques to support the manufacture and supply of safety-related components. These include:

- Not developing a full understanding of the design requirements
- Assuming that a reverse-engineered component is identical to the original equipment manufacturer (OEM) component even though it was not subject to the same design and manufacturing specifications and processes as the original component
- Assessing only the physical attributes of the component without properly evaluating the functional design requirements
- Not passing on all relevant design requirements to the supplier
- Not verifying that all safety-related design requirements have been met, either by testing or analysis

The process, included in this report, for using reverse-engineering techniques is intended to address these concerns.

1.5 Background

Use of reverse-engineering techniques is one of the more powerful tools available to the commercial nuclear power generation industry to mitigate the impact of obsolescence and aging assets. However, it can also be a controversial and often misunderstood activity. It is common for individuals well experienced in reverse-engineering activities to disagree on what exactly the term *reverse engineering* means and the activities it encompasses.

Reverse-engineering techniques are used by many industries for many different reasons. Reverse engineering has existed for thousands of years, perhaps since the first time soldiers faced opponents with superior weapons. To this day, reverse-engineering techniques are used by the military. For example, a military force might use reverse-engineering techniques to analyze an enemy's superior weapon to develop an equivalent weapon, or the same reverse-engineering techniques might be used to determine the best means to defeat or destroy the superior weapon. Of course, the military also uses reverse engineering for the same primary reason as the nuclear industry—to combat obsolescence.

As is the case with the term *reverse engineering*, the term *obsolete* has several colloquial meanings. At the time this report was published, 3-1/2" floppy disks could still be purchased, but most people would agree that this type of data storage media has long been rendered obsolete. Unless specified otherwise, references to the words *obsolete* or *obsolescence* in this report refer to something that is no longer commercially available or is otherwise difficult to acquire. As examples, obsolete items may be available only in the surplus marketplace as used or refurbished, or available only at an excessive cost or unacceptable lead time.

Causes of obsolescence vary, but obsolescence typically results when demand for a product decreases to the point where it is no longer economical to supply the product. Regardless of the cause, obsolescence challenges the ability to procure replacement items for aging assets. The commercial nuclear industry typically applies reverse-engineering techniques to facilitate replacement of obsolete items at both the component and part levels.

1.6 Applications for Reverse-Engineering Techniques

MIL-HDBK-115, Department of Defense handbook, U.S. Army, Reverse Engineering Handbook, (guidelines and procedures) [3] defines *reverse engineering* as "the process of duplicating an item, functionally and dimensionally, by physically examining, measuring existing parts, and reviewing available information, to develop the technical data (functional, physical, and material characteristics) necessary to manufacture an item or component."

Application of reverse-engineering techniques may be applied to safety-related, augmented quality, and non-safety-related items.

The basic purpose for using reverse-engineering techniques in the commercial nuclear industry is to facilitate obtaining replacement parts and equipment. Although the term *reverse engineering* can be used to refer to a number of activities or processes, this report focuses on use of reverse-engineering techniques to support the maintenance and operation of commercial nuclear facilities. Reverse-engineering techniques may be applied in commercial nuclear power facilities for several reasons. A few of the most common reasons include:

- Developing information necessary to accurately specify an item for subsequent procurements to enable the use of alternate sources
- Developing acceptance criteria for use in commercial grade item dedication
- Facilitating fabrication of an equivalent replacement item

Reverse-engineering techniques can also be used for other purposes, such as informing failure investigations.

Table 1-1 lists examples of activities commonly referred to as *reverse engineering*.

Reverse-engineering techniques are most often associated with the replacement of mechanical parts and electronic components.

Many types of mechanical equipment require spare parts for routine maintenance or repairs. Obsolete mechanical equipment is capable of functioning as designed for many years as long as the spare parts required for proper maintenance can be obtained. Therefore, reverse-engineering techniques are used to obtain replacement items such as a fastener, impeller, and valve stem or hinge pin necessary to maintain components such as pumps, engines, valves, etc. Reverse-engineering techniques can be used to recover design information necessary to fabricate or procure a replacement that will perform its design functions. It is impossible to guarantee that reverse-engineering techniques will result in obtaining an exact duplicate absent a complete set of original design drawings and manufacturing information. However, careful use of reverse-engineering techniques is an established method of producing replacement items that perform the required design functions.

Most new electronic and electrical equipment includes digital or microprocessor-based technology. Design changes to enable use of digital technology in existing plant systems require a very long lead time and present complexities such as verification and validation. Furthermore, systems designed to run on analog technology may not always perform as expected when digital replacement items are used. Therefore, reverse-engineering techniques are used to enable the replacement of obsolete electronic devices. Different challenges are associated with the use of reverse-engineering techniques for electrical and electronic equipment. Due to the rapid evolution of discrete electronic parts and devices, fabrication of an exact duplicate is often not possible. Even if a complete set of original design drawings and manufacturing information is available, the discrete components called for in the original design are often obsolete. When using reverse-engineering techniques to facilitate replacement of electrical and electronic items, it is recognized at the onset of this effort that a new design may be required to fabricate an equivalent replacement.

At a minimum, the use of reverse-engineering techniques involves a process to determine sufficient information about an item to accurately specify it, manufacture it directly, or design a fully functional replacement.

Table 1-1
Activities Associated with the Term *Reverse Engineering*

Activity	Purchase an item with known attributes or design from a different supplier	Recover characteristic information for dedication	Produce a functionally equivalent "part" (simple item)	Produce a functionally equivalent "component" (complex item)
Description	• Capturing information that is necessary about an item to create a purchase specification. • Examining a standard product or its specification to identify information needed to purchase it directly from a manufacturer or alternate source. • Purchasing an item directly from a manufacturer or alternate source.	• Examining a specimen to identify acceptance criteria/characteristics pursuant to the commercial grade dedication process.	• Recovering information about a part so that a functionally equivalent part can be fabricated and installed in existing equipment.	• Recovering information about a component so that a functionally equivalent component can be fabricated and installed in existing equipment.
Purpose	• Expanding supplier options, reduce cost or lead time.	• Recovering information about the item's original design characteristics to help establish acceptance criteria.	• Recovering information about the item's original design so that a fully functional replacement can be fabricated.	• Recovering information about the component's original design so that a fully functional replacement can be fabricated.
Example	• Recovering information about a fastener, O-ring, or drive belt so that it can be purchased from a different source.	• Using Fourier transform infrared spectroscopy (FTIR) to determine material type. • Examining surface finish to determine machining process used to fabricate.	• Recovering dimensional and material information from an existing motor-operated valve stem nut and creating drawings so that a machine shop can create a replacement.	• Recovering dimensional, material and functional information from an existing circuit card, prototyping and fabricating a replacement.
Conditions/ Boundaries	• Items are fabricated in accordance with standards or known design parameters.	• The information is used for commercial grade dedication.	• The item is simple in design requiring only dimensional and material of construction information.	• The component is complex in design; multiple parts must interface to achieve function.
Design	• Same design.	• Same design.	• Functionally equivalent or new design.	• Functionally equivalent or new design. • Consider system design basis information if available.

2
PRELIMINARY CONSIDERATIONS

2.1 Legal Considerations

Legal issues such as patent infringement, unauthorized use of intellectual property, and theft are considerations when embarking on a project that involves the use of reverse-engineering techniques. Legal violations are not inherent in the use of reverse-engineering techniques. In fact, the U.S. government uses reverse engineering to support aging assets as documented in MIL-HDBK-115C [3]. Although some basic information on patents is included this report, **appropriate legal counsel should be sought as necessary prior to using reverse-engineering techniques**.

All patents are registered with the U.S. Patent/Trademark Office. An issued patent contains all the specifications and drawings needed to manufacture the item. A patent is a right granted to an inventor by the government to exclude others from making, using, or selling the invention for a period of 20 years from the earliest filing date claimed in the patent. Granting a patent is not granting the positive right for the inventor to make, use, or sell the invention, but only the right to prevent others from doing so. The inventor obtains only the legal right to sue other parties for infringement of the patent. Generally, remedies for the inventor include monetary compensation for the use of the patented item and injunctive relief (the ability to prevent a non-licensed reverse-engineered item from being used). Once patents have expired, the item becomes public domain and can be manufactured or produced by anyone without concerns for litigation. However, representing reverse-engineered items as authentic OEM items without the legal right to do so may be considered as a form of fraud or counterfeiting.

2.2 Licensee and Supplier Responsibilities

Reverse-engineering techniques are employed by licensees and by organizations in a licensee's supply chain. Licensees typically implement reverse-engineering techniques to support operation and maintenance of aging equipment. Reverse engineering can be used to help address obsolescence and unacceptable lead times. Licensees can enlist the support of suppliers that specialize in the use of reverse-engineering techniques when the licensee does not possess the expertise or specialized equipment necessary to perform the reverse-engineering activities.

Suppliers may implement the use of reverse-engineering techniques to address the needs of a single customer or to develop generic replacement options to meet the needs of multiple customers.

In either case, the licensee remains responsible for ensuring that the reverse-engineered item is suitable for its particular application through the implementation of design control activities. However, suppliers face additional considerations when using reverse-engineering techniques to offer a generic replacement item. Table 2-1 includes examples of customer and supplier responsibilities in typical scenarios.

Table 2-1
Customer and Supplier Responsibilities for Typical Scenarios

Design Information	Scenario	Customer Responsibilities	Supplier Responsibilities	Plans to Market as an "Aftermarket" Basic Component Replacement
Item design is known.	• Customer provides complete design information. • Manufactured to industry standard.	• Customer provides complete design. • Customer maintains design control (procurement evaluation, equivalency evaluation, design equivalent change or design change).	• Supplier does no design work. • Supplier manufactures to customer design. • Supplier certifies to customer design.	• Supplier publishes product capabilities/ specifications. • Supplier verifies suitability of design for published capabilities (testing, design review, alternate calculations).
Item design is unknown.	• Customer provides working/ non-working specimen and/or specimen purchased from alternate source. • Customer provides quality and technical requirements/equipment specification.	• Customer verifies that supplier is approved to provide reverse-engineering services. • Design responsibility is addressed in the purchase order. • Customer Engineering approves design. • Customer maintains design control (equivalency evaluation, design equivalent change or design change). • Customer provides applicable interface requirements.	• Supplier recovers design information. • Supplier verifies suitability of design for identified functions (testing, design review, alternate calculations). • Supplier submits design to customer for approval.	• Same as above.

2.3 Coordination Between the Licensee and the Supplier

Coordination between the licensee and the supplier should begin as early as possible when applying reverse-engineering techniques. Examples of forms that can be used to assist in the collection of pertinent information are included in Appendices A and B.

Coordination is necessary to:

- Develop design requirements
- Clarify expectations between the organizations regarding implementation of the reverse-engineering techniques
- Communicate interface requirements
- Establish responsibility for testing, particularly when testing will be conducted at more than one location

Additional guidance stressing the importance of communication between the licensee and supplier is provided in Section 3 of this report.

2.4 Complexity and Risk Considerations

2.4.1 Inherent Risk

Use of reverse-engineering techniques to facilitate replacement of components and other complex items can introduce risk. There is always risk that an aspect of the original design could be overlooked or incorrectly interpreted. Conversely, alternatives to using reverse-engineering techniques such as deferring maintenance due to the unavailability of replacement items, repeatedly repairing items such as printed circuit boards, or implementing design changes can also introduce risk.

2.4.2 Risk Versus Cost and Schedule

Use of reverse-engineering techniques is frequently cited as a cost-savings measure. However, recognized savings are typically associated with avoiding the cost of other alternatives. For example, the costs of using reverse-engineering techniques to replace an obsolete pump impeller are less than the costs associated with replacing an entire pump. Likewise, the costs associated with use of reverse-engineering techniques to inform the design of an analog replacement for an obsolete power supply are less than the costs associated with procuring and qualifying a current-model power supply that uses digital technology.

Savings associated with use of reverse-engineering techniques to replace complex items are rarely per-unit cost savings. Use of reverse-engineering techniques introduces costs that the plant would not incur if procuring an item from the OEM. These costs may include the process of using reverse-engineering techniques, the cost of destroying at least one specimen, and the cost of associated engineering evaluations such as equivalency evaluations, design equivalent changes, design changes, equipment qualification, and so forth. These costs add significantly to per-unit cost as they typically apply to a small quantity of replacement items.

Reverse-engineering projects are also undertaken to reduce lead time. An OEM may be unwilling to interrupt their normal production process to manufacture a spare part for equipment they no longer produce. Reverse-engineering techniques can be used to successfully obtain relatively simple replacement items. It is unlikely that lead time for the initial purchase will be

reduced in cases where reverse-engineering techniques are used to develop a replacement with a new or complex design. However, subsequent orders for the redesigned item may in fact be quicker, so reverse engineering may be more suited when repeat orders for a redesigned item are anticipated.

2.4.3 Risk of Unsuccessful Outcome

In addition to risks associated with safety, the possibility of an unsuccessful outcome exists when applying reverse-engineering techniques. Significant resources can be expended on a project only to find that sufficient information cannot be obtained to successfully develop the information required for a replacement item. The risk of a successful project is directly proportional to the complexity of the item for which reverse-engineering techniques are being applied. For example, a stem for a valve is a relatively simple item with good chances for a successful outcome. On the other hand, an electronic pressure transmitter circuit board, which is required to be environmentally qualified, is a relatively complex device with special considerations for not only the design but also the environment in which the item must function. Application of reverse-engineering techniques to replace this type of complex device must be entered into cautiously with a realistic sense of available resources and the probability of success.

Reverse-engineering techniques can be successfully applied with sufficient time, allocated resources, and, in some cases, iterations; however, other alternatives, such as component modifications and alternate replacements, should also be considered and evaluated when deciding if reverse-engineering techniques should be applied.

The amount and type of data available also directly influence risk. The more detailed data available, the lower the inherent risks of applying reverse-engineering techniques. For example, if the available data appear complete and identify all critical characteristics for design including associated tolerances, then all that would be needed is to verify the data against the actual item. In this scenario, the risks are low due to the amount of data available. However, assume that no data are available for the item for which reverse-engineering techniques are being applied. Then, all data would have to be developed from inspecting and testing the item. This is not an impossible scenario for very simple items, but it substantially increases the risk of reverse engineering the item.

Most reverse-engineering projects fall somewhere between these two extremes—where some data are available but require enhancement, and some data need to be developed. For example, a drawing could be available that identifies most dimensions but does not identify tolerances or surface finishes sufficient for manufacturing. This would require some data development to determine manufacturing tolerances, fits, and surface finishes.

2.4.4 Factors and Resulting Risk

Table 2-2 illustrates several factors that may be considered during the implementation of reverse-engineering techniques that can affect risk and the ability of the reverse-engineered replacement item from performing its design functions.

Figure 2-1 provides a representation of the relative risk of complexity and risk factors. Complexity and risk factors are listed in approximate order of impact starting with “passive function” (approximate lowest risk/complexity) and ending with “digital content” (approximate highest risk/complexity). Applicable factors should be considered prior to embarking on a project that involves use of reverse-engineering techniques to provide an indication of how complex the project may be, as well as an indication of the risk that the project may not be successful.

Table 2-2
Factors and Resulting Risk

Factor	Risk
Safety classification (Safety, non-safety)	Potential risk to nuclear safety function of the item
Functional mode (active, passive)	Risk of failure to address interface considerations and requirements for the item
Equipment qualification (seismic, environmental, electromagnetic, or radiofrequency interference)	Risk of failure to establish or maintain item’s equipment qualification
Level of design detail available (specification, dimensions, materials, drawings, manufacturing information). Is item a system, component, part, material?	Risk of failure to consider an important aspect of design since less design detail is available for items that are below the purchase level of assembly
Criticality classification, (critical component, single-point vulnerability)	Risk to critical function of the item
Relationship of geometry to design	Risk of interference, for example, due to thermal expansion, and so forth

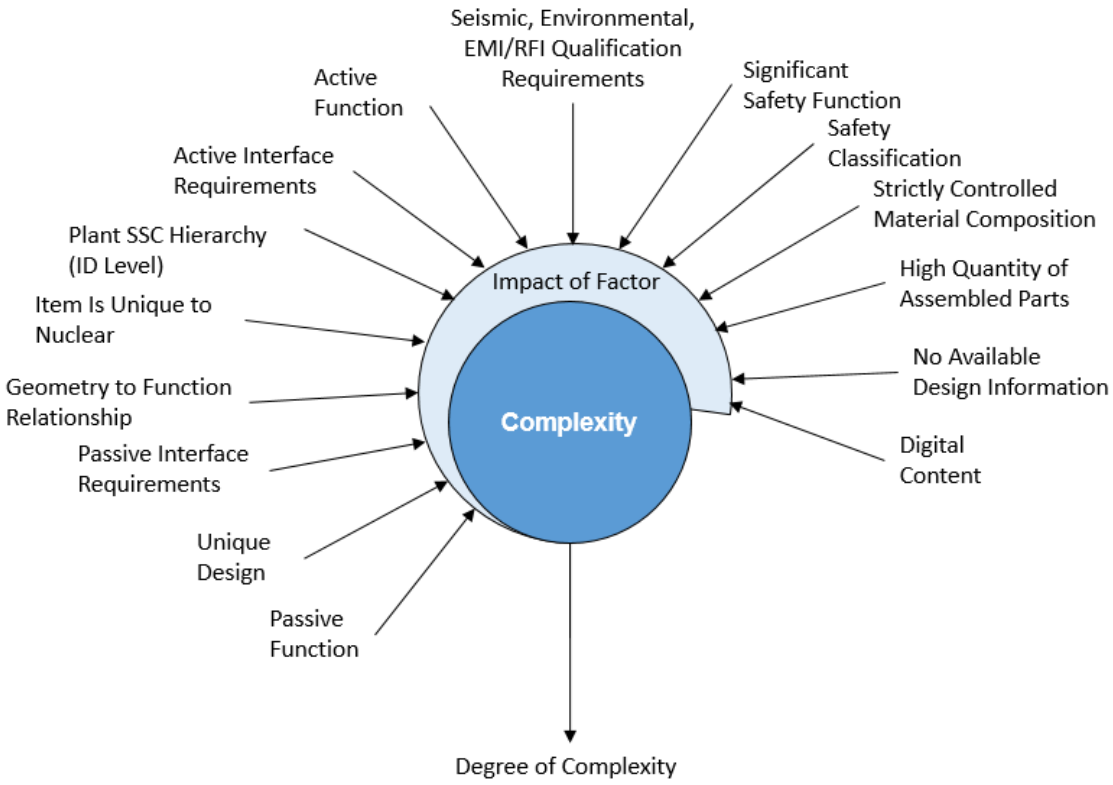


Figure 2-1
Relative Impact of Complexity and Risk Factors

2.5 Reverse-Engineering Team

The risks and factors associated with the item and its applications should be considered when assembling a reverse-engineering team so that the types of expertise required to apply reverse-engineering techniques can be identified prior to starting the process. The types of technical personnel and expertise that should be enlisted are determined by:

- The item being reverse engineered (for example, electrical, mechanical)
- The complexity of the item
- The reason for using reverse-engineering techniques

Reverse-engineering teams are typically ad hoc and should include the experience and expertise necessary for successful completion of the project. In some cases, enlisting the aid of an external organization with experience is necessary. Teams that apply reverse-engineering techniques might include:

- Circuit/electrical design
- Computer-aided design and drafting
- Engineers (procurement, manufacturing, design, system, component, and so forth)
- Inspectors
- Machinists

- Manufacturer representatives
- Mechanics
- Quality assurance/control (QA/QC) personnel
- Technicians

Once a project is underway, changes in team composition should be minimized to avoid rework and delays. This is especially important for projects that are complex in nature or require specialized skills.

Personnel that possess hands-on experience with a particular type of item or equipment should not be overlooked during selection of the team. Individuals such as mechanics and technicians can bring valuable detailed knowledge to the team from the equipment perspective as well as the day-to-day operation, maintenance, and interface requirements.

Machinists are invaluable in determining optimum fabrication methods, fits, and tolerances of components. Procurement and component engineers bring detailed knowledge about equipment, manufacturers, and industry procurement methods. Metallurgists are indispensable in determining material characteristics, surface coatings, surface finishes, and welding techniques.

System engineers can bring "end-user" perspective to the team and may possess undocumented knowledge about function.

Licensee design experience is typically at the system level and involves design-basis requirements for a component as opposed to designing the component itself. Licensee personnel that may have system and plant design experience may not have component design experience. Component design and manufacturing experience is recommended for complex projects involving the use of reverse-engineering techniques. In some cases, reverse-engineering activities used to recover the design of the original item may be subcontracted to organizations with the appropriate equipment, expertise, and experience.

3
USE OF EXTERNAL RESOURCES AND THE IMPORTANCE OF EFFECTIVE COMMUNICATION

The purpose of this section is to stress the importance of effective communication and exchanges of information between the licensee and supplier throughout the implementation of a reverse-engineering project. Effective exchange of information facilitates the successful implementation of the process (flow charts) in Section 4 of this report.

3.1 Use of External Resources

External resources such as suppliers that specialize in reverse-engineering techniques for particular types of items can be engaged to assist with complex or specialized reverse-engineering projects. The decision to enlist external resources for a particular project depends upon each licensee's internal capabilities, resources, and needs.

It may not be cost-effective for licensees to acquire the capital equipment and develop the technical resources necessary to perform reverse-engineering and manufacturing activities for a wide range of equipment and item types. Therefore, suppliers that specialize in certain types of equipment are sometimes enlisted to assist with reverse-engineering projects. This can reduce risk and be an effective approach for complex items such as electronic equipment, pumps, and motors.

Computed tomography (CT) scanning is an advanced nondestructive technology that can be applied to visualize interior features of solid objects, recover highly accurate (± 0.001 inch or 25.4 microns) digital information on their geometries, and convert the digital information into fabrication drawings or models. However, applying CT technology to reverse-engineering projects may not be practical, given that the capital costs for CT equipment can range from $1.2M–$1.8M. Therefore, services of an external entity that could provide CT scanning might be enlisted for a complex reverse-engineering project.

The level of engagement of external resources in a reverse-engineering project can range from providing a specific inspection, analysis, or test to overall responsibility for design and fabrication of the replacement item. Some large-scale reverse-engineering projects, for instance, replacement of major pump components such as shafts, impellers, and wear components, can be performed as a turnkey project under the auspices of the supplier's 10CFR50 Appendix B–compliant [4] quality assurance program. In some cases, suppliers specializing in the application of reverse-engineering techniques can engage multiple customers to distribute costs.

Effective communication between the licensee and external resources involved in a reverse-engineering project is essential, regardless of the level of engagement.

3.1 Initial Information Communicated Between the Licensee and Supplier

3.1.1 Interface Plan

An interface plan should be developed when more than one party is involved in a project employing the use of reverse-engineering techniques. The complexity of the plan will vary based on the complexity of the item. The following information should be collected as a preliminary step when two parties, such as a licensee and a supplier, initiate a project involving the use of reverse-engineering techniques.

- What is the item's short technical description?
- Who is the original manufacturer of the item?
- Who is the original supplier of the item?
- What is the item's part and model number, type, etc.?
- What is the item's intended end-use application(s)? It is a good practice to request the licensee to provide a specific end-use application, such as equipment tag number(s).
- Are there other possible end-use applications for this item that should be considered?
- Can the customer provide specimens to the supplier? If yes, how many and in what condition are they in (working, used, broken, and so forth)?
- Can the customer provide digital photos of the item showing clearly its nameplate and any markings?
- If the item has serial numbers assigned, request that a specimen be supplied with a serial number that is typical of serial numbers found on originally provided equipment.
- Is the item a component, a part, or material as defined by the American Society of Mechanical Engineers (ASME), Section III [5]?
- What is the safety classification of the item?
- What is the known safety function(s) or design function(s) of the item?
- Is the item governed by the plant's technical specifications or final safety analysis report (FSAR) commitment?
- What is the desired quantity of replacements that will be eventually ordered?
- Can the customer test the item to verify end-use application requirements without installing it in the plant?
- What is the installed environment (such as radiation dose level, temperature, humidity, etc.)?
- What equipment qualification requirements apply such as environmental, seismic, electromagnetic/radio frequency interference (EMI/RFI)?
- What are the in situ conditions? (for example, degraded voltage, etc.)
- Are original datasheets/specifications available?
- Is the supplier able to determine all inputs/outputs?

- What data is the supplier responsible for?
- What data is the licensee responsible for?
- Is the item still being manufactured?
- Is operating experience (OE) known and can it be shared?

3.1.2 Documenting the Initial Exchange of Information

An example of a form designed to facilitate the initial exchange of information between the licensee and supplier is included in Appendix A of this report. The form prompts for pertinent information including:

- Contact information
- Item identification information
- Item technical information
- Availability and condition of specimens that can be examined
- Availability and condition of interfacing items that can be examined
- Available information and documentation about the item
- Purpose for use of reverse-engineering techniques
- Types of testing and examination anticipated

The form in Appendix A could be initiated by either the supplier or licensee, because, in many instances, the reverse-engineering team includes both licensee and supplier personnel. This form is provided as an attachment to this report.

3.2 On-Going Communication of Information

It is beneficial to continue the exchange of information between the supplier and licensee throughout the process for application of the reverse-engineering techniques described in Section 4 of this report. The form included in Appendix B can be used to document information as it is recovered, identified, or verified during the process. Because the information is added throughout the process, the form can be considered a “living document” that is updated when needed and shared among stakeholders in the process.

3.3 Communication of Reverse-Engineering Output

The results (final outputs) yielded from application of reverse-engineering techniques should be shared with all entities involved in the project. This is especially important when more than one organization (for example, a licensee and a supplier) are involved in the reverse-engineering effort. Step 4.3.8 in Section 4 of this report provides guidance on how reverse-engineering outputs can be finalized, documented, and communicated.

Reverse-engineering output is typically used to develop a specification for the replacement item. This technical information is typically included in procurement documents for the replacement item and may be supplemented with supplier quality and documentation requirements.

For items manufactured in accordance with industry standards such as fasteners, the output may be as simple as an enhanced description for use in future procurement documents. For simple items, such as machined replacement parts, the output may consist of fabrication drawings and manufacturing information. For more complex items such as components, reverse-engineering outputs may include any of the following:

- Bills of material
- Procurement documents for items furnished by sub-suppliers
- Supplier audit/evaluation results/reports
- Qualification test records and results
- Component-level specifications
- Prototype test results
- Certification
- Nonconformance/deviations and corrective action

4
DETAILED PROCESS FOR USING REVERSE-ENGINEERING TECHNIQUES

The purpose of this section is to provide expanded guidance on the steps involved in the application of reverse-engineering techniques. The guidance is presented in the form of process maps with numbered steps that correspond to the numbers of the paragraphs in the narrative that describes each step. The process is intended to provide a logical sequence and to present important factors that should be considered when applying reverse-engineering techniques. However, certain activities may be completed in parallel or the sequence may vary. Therefore, the process is not intended to be used as a procedure or audit checklist. Table 4-1 summarizes the figures contained in this section, the content for each figure, the major steps associated with each figure, and the detailed steps where applicable.

Table 4-1
Process Flow Charts for the Use of Reverse-Engineering Techniques

Page	Content		Major Step(s)	Detailed Steps
4-2	Figure 4-1	Process Map Key	Overview	Not applicable
4-3	Figure 4-2	Process for the Application of Reverse-Engineering Techniques	4.1–4.9	Not applicable
4-13	Figure 4-3	Determine the Original Item's Design Characteristics	4.2	4.2.1–4.2.7
4-26	Figure 4-4	Establish/Vet the Replacement Item Design, page 1 of 2	4.3	4.3.1–4.3.5
4-27	Figure 4-5	Establish/Vet the Replacement Item Design, page 2 of 2	4.3	4.3.6–4.3.10
4-38	Figure 4-6	Determine the Design Control Activity, page 1 of 2	4.4	4.4.1–4.4.5
4-39	Figure 4-7	Determine the Design Control Activity, page 2 of 2	4.4	4.4.6–4.4.8

Figure 4-1 is a key that explains the functions of the various graphic elements used in subsequent figures that present the process flow chart. The major steps in the use of reverse-engineering techniques are depicted as numbered boxes in Figure 4-2. More detailed, second-level process diagrams are included in Figures 4-3 through 4-7 for each step in Figure 4-2 that is depicted by a colored box (a box that is not white or gray). For example, Step 4.2, Identify the original item's design characteristics, is depicted in a green box. More detailed steps explaining how to identify an item's original design characteristics are shown in Figure 4-3 by green boxes representing Steps 4.2.1–4.2.7. The narrative text following each process flow chart provides information on how to accomplish each step.

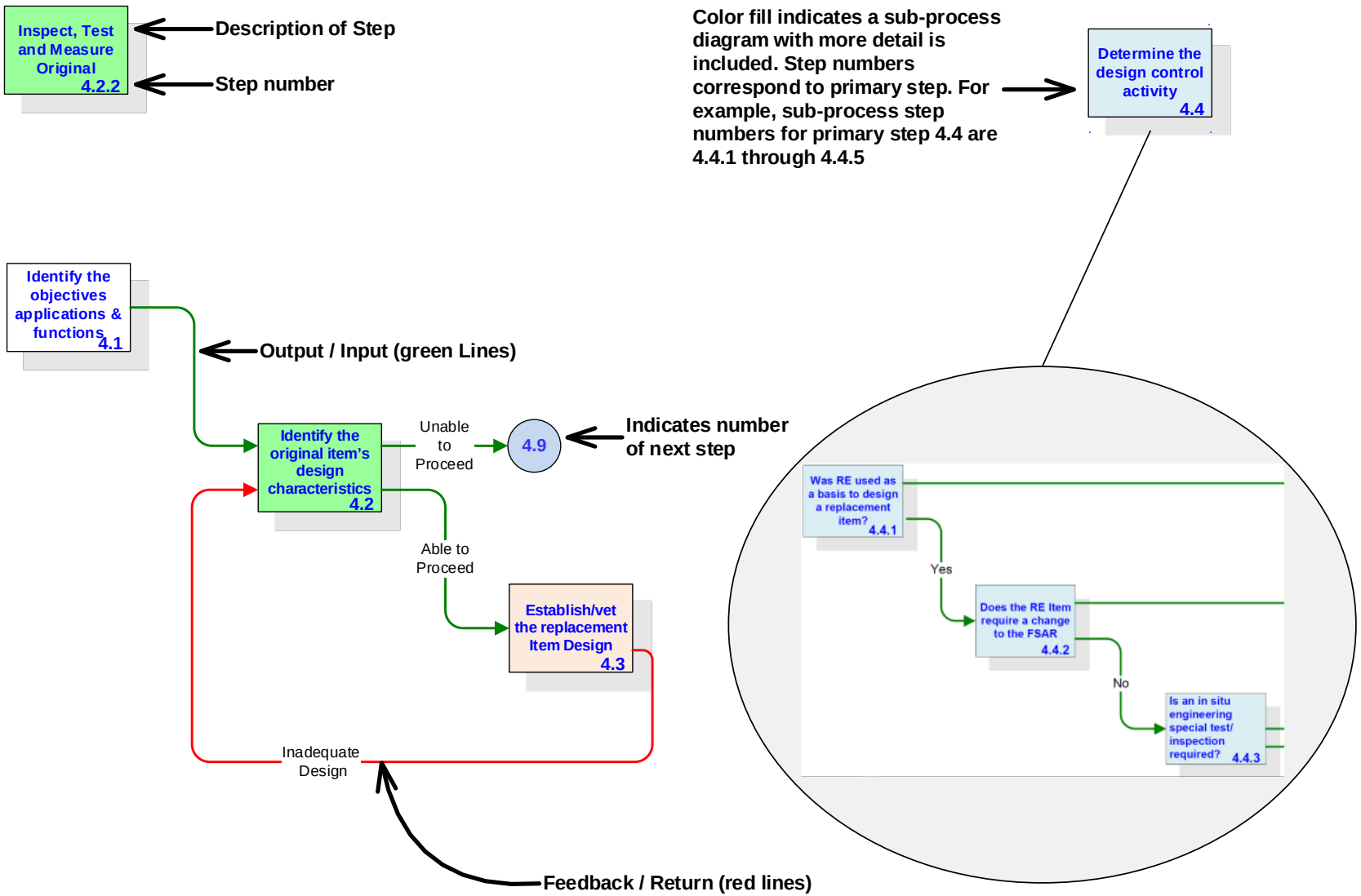


Figure 4-1
Process Map Key

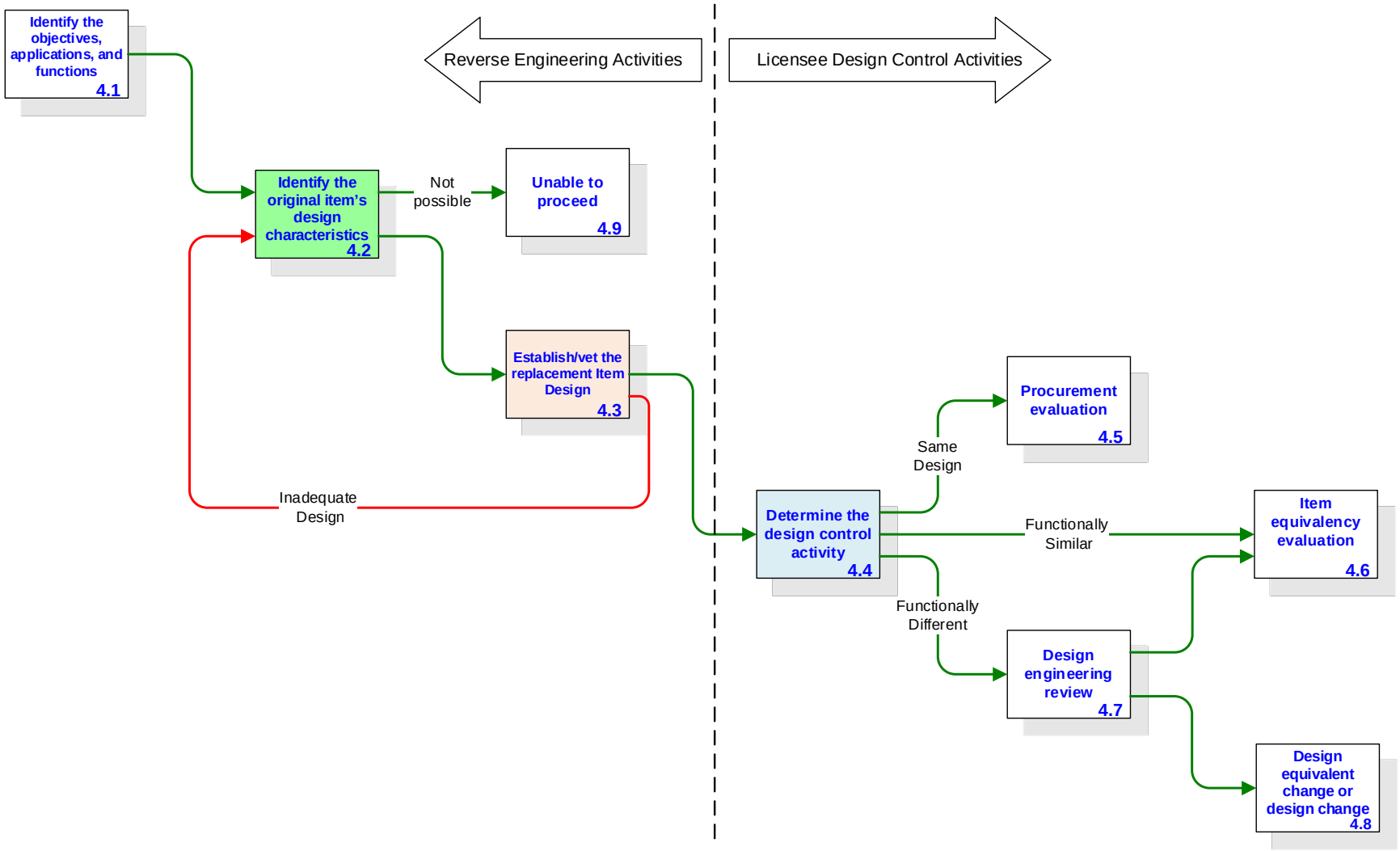
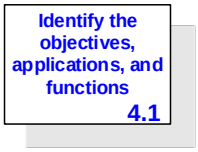


Figure 4-2
Process for the Application of Reverse-Engineering Techniques

4.1 Identify the Objectives, Applications, and Functions



Description

The objectives of applying reverse-engineering techniques are identified and documented along with the end-use applications and functions of the item for which reverse-engineering techniques are being applied. Identification of applications and design functions (including any safety functions as applicable) is important because this information is necessary to complete subsequent process steps.

Methodology

The objectives for applying reverse-engineering techniques should be determined and clearly documented. Typical objectives include:

- Developing information necessary to accurately specify an item for subsequent procurements in order to enable the use of alternate sources
- Developing acceptance criteria for use in commercial grade item dedication
- Facilitating fabrication of an equivalent replacement item

Use of reverse-engineering techniques to facilitate fabrication of an equivalent replacement item can be resource and time intensive as it may involve developing a prototype, establishing suitability of design, and conducting manufacturing activities.

Once the objective is determined, potential end-use applications of the item in the plant are identified. Existing documents such as the plant's master equipment list (MEL); classification of critical structures, systems, and components (CSSC) list; Q-list; environmental qualification (EQ) list; valve list; relay list; or other existing equipment or spare parts databases can be used to perform this task. The end-use applications should be evaluated because the operating environment and function for similar devices can vary widely from application to application.

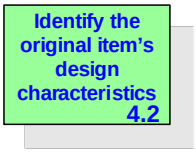
The functions associated with each end-use application need to be identified. Understanding the function of the item is fundamental to developing the design characteristics and implementing the reverse-engineering techniques described in this report.

Upon completing this step, continue to Step 4.2, Identify the original item's design characteristics.

Precautions/Lessons Learned

- It is important to identify the most restrictive end-use application to ensure that applicable qualifications such as seismic, environmental, EMI, and RFI are considered.

4.2 Identify the Original Item's Design Characteristics



Description

Recovering enough information about the original item to enable procurement of a replacement that is capable of performing the same functions is the primary objective of using reverse-engineering techniques.

Methodology

Most reverse-engineering techniques are used to identify design characteristics of the original item. Identification of the original item's design characteristics typically involves review of any available documentation, visual examination of specimens of the original item, and inspections and tests to determine the item's characteristics.

In Section 4.10 of this report, Figure 4-3 and Steps 4.2.1 through 4.2.7 include a detailed second-level process that addresses identification of the original item's design characteristics.

The term *design characteristics* is defined as those properties or attributes essential for the item's fit, form, and functional performance. In other words, design characteristics are the identifiable and/or measurable attributes of a replacement item that provide assurance that the replacement item will perform the same design functions as the original item it is replacing. Identification of design characteristics should be based upon the most severe application, installed environment, and end-use application of the item in the plant.

Design characteristics should address the plant's applicable EQ design basis conditions and required seismic response spectra are significant when identifying the appropriate design characteristics. Particular attention should be devoted to the types of materials (that is, material chemical and physical properties) used in harsh environments and seismically qualified applications. A failure modes and effects analysis (FMEA) may be helpful in deriving the appropriate design characteristics. As noted above, Figure 4-3 illustrates the seven steps associated with identification of the original item's design characteristics.

In certain cases, it may not be feasible or possible to identify design characteristics due to the absence of a specimen, absence of sufficient information, complexity of the item, cost, or unavailability of required technology. If it is determined that identification of sufficient design characteristics is not possible after completing Steps 4.2.1 through 4.2.7, proceed to Step 4.9, Unable to proceed, and consider other replacement alternatives. If sufficient design characteristics are recovered, continue to Step 4.3, Establish/vet the replacement item design.

Precautions/Lessons Learned

- Coordination between the licensee and the supplier is essential in understanding the design functions and the design characteristics of the item. Communicating end-use information and component/system interfaces to a supplier is also beneficial when deriving the appropriate design characteristics for the item being reverse engineered. The organization leading the reverse-engineering effort may need to walk down the end-use applications to fully understand the unique design characteristics or variances of those characteristics.

4.3 Establish/Vet the Replacement Item's Design



Description

Design characteristics identified from the original item are used to establish design information for the replacement item. In most cases, the reverse-engineering entity is not in possession of original design and manufacturing information. Therefore, it is imperative to review design information and characteristics recovered through Steps 4.2.1 through 4.2.7 (Figure 4-3) to identify, address, and document any gaps or assumptions in the recovered design information. Establishing and vetting the replacement item design is intended to establish confidence that the replacement item design addresses applicable design functions, accounts for actual in situ conditions and environment, identifies and reconciles unknown design parameters, addresses applicable interfaces, and establishes adequate tolerances.

Methodology

Figure 4-4 and Figure 4-5 and Steps 4.3.1 through 4.3.11 present the detailed second-level process associated with establishing and vetting the replacement item design. These steps prompt consideration of aspects important to the design and function of the item.

If Steps 4.3.1 through 4.3.11 reveal aspects of the replacement item design that are incomplete or inadequate, return to Step 4.2, .Identify the original item's design characteristics. Otherwise, continue to Step 4.4, Determine the design control activity.

Precautions/Lessons Learned

- It is important to consider the extent of design verification necessary. Guidance can be found in Section 6.2 of ANSI N45.2.11 – 1974 [6] endorsed in U.S. NRC Regulatory Guide 1.64 [7] NQA-1, Part I, Requirement 3, Section 500 [8], endorsed in U.S. NRC Regulatory Guide 1.28 [9].

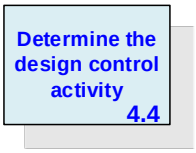
  > "The extent of the design verification required is a function of the importance to safety of the item under consideration, the complexity of the design, the degree of standardization, the state-of-the-art, and the similarity with previously proven designs. However, the applicability of standardized or previously proven designs, with respect to meeting pertinent design inputs, including environmental conditions, shall be verified for each application. Where the design of a particular structure, system, or component for a

particular nuclear power plant has been subjected to a verification process in accordance with this standard, the verification process need not be duplicated for identical designs. However, known problems affecting the standardized design and their effects on other features shall be considered. The original design and associated verification measures shall, however, be adequately documented and referenced in the files of subsequent application of the design.

Where changes to previously verified designs have been made, design verification shall be required for the changes, including evaluation of the effects of those changes on the overall design Communication and exchange of design information between the licensee and the supplier is important when vetting the effective implementation of reverse-engineering techniques."

- Missing information or unverified assumptions associated with design characteristics should be clearly communicated and understood by both the licensee and supplier.
- Prototype testing may be considered at this or any point in the process to close the gap associated with any unverified assumptions made by either the supplier or licensee. Prototype testing conditions should be consistent with end-use design conditions.

4.4 Determine the Design Control Activity



Description

Although the intent of reverse-engineering projects is often to develop an equivalent replacement for the original item, the design of nuclear facilities must be controlled in accordance with 10CFR50, Appendix B [4], Criterion III, Design Control. Determining the design control activity involves selection of the process used to document design control. Design control is typically documented in a procurement evaluation, an equivalency evaluation, design equivalent change, or a design change. Typical evaluations that involve application of reverse-engineering techniques are summarized in Table 4-2, along with examples, level of design information involved, methods used to recover information, and typical output documentation associated with each evaluation. The type of evaluation selected may vary based on licensee or site-specific internal procedures and processes for controlling design.

Methodology

In Section 4.12 of this report, Figure 4-6 and Figure 4-7, and Steps 4.4.1 through 4.4.8 include a detailed second-level process for determining the appropriate design control activity. Following the detailed process included in paragraphs 4.4.1 through 4.4.8 will result in selection of a procurement evaluation (Step 4.5), an item equivalency evaluation (Step 4.6), or a review by design-qualified individuals (Step 4.7) to determine if an item equivalency evaluation or a design change (Step 4.8) is appropriate.

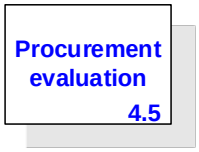
Precautions/Lessons Learned

- From a supplier's perspective, it is important that the documentation provided with the replacement item satisfies the licensee's purchase order requirements. This could include equivalency evaluations, test reports, and other documentation associated with testing or inspection imposed in the purchase order.
- The activities and the sequence of each process may vary, depending on the type of item being reverse engineered using existing processes/procedures developed by each licensee.

Table 4-2
Typical of Evaluations Associated with Design Control and Use of Reverse-Engineering Techniques

	Procurement Evaluation	Item Equivalency Evaluation	Design Equivalent Change	Design Change
Examples of Items Typically Involved	Materials and parts identified with OEM part number, but manufactured to meet industry-standard specifications, for example, fasteners, fittings, O-rings, resistors, capacitors, and so forth.	Gaskets, machined parts (typically with no active function), such as thermocouples, thermowells, component piece-parts, and so forth.	Complex items that have characteristics within the bounded technical requirements or functions, such as valves, pumps, relays, printed circuit boards, and so forth.	Items that may have different functional characteristics from the original item that are outside bounded technical requirements.
Level of Design Information Typically Involved	Material and physical characteristics. Applicable standard specifications. For example, American Bearing Manufacturers Association (ABMA), American Institute of Steel Construction (AISC), American Society for Testing Materials (ASTM), German Institute for Standardization (DIN), European Committee for Electrotechnical Standardization (CENELEC), and so forth.	Available OEM design information and application information that can be used to determine and evaluate characteristics necessary to establish the proposed replacement is equivalent to the original.	Available OEM design information and theory of operation, original plant design requirements (data sheets, equipment specifications, etc.), operating environment and conditions, equipment qualification reports, and similar information that can be used to determine characteristics necessary for the item to perform its design function(s) in its intended application(s).	Original plant design requirements (data sheets, equipment specifications, etc.), operating environment and conditions, and similar information that can be used to determine characteristics necessary for the item to perform its design function(s) in its intended application(s). Qualification parameters (seismic, environmental, EMI/RFI). Development of detailed design requirements, post-installation/in situ testing requirements, and similar information necessary to establish that the item will perform its design function(s) in its intended application(s).
Typical Methods Used to Recover Information	Review of OEM and original equipment supplier (OES) documentation, identifying information on the item and packaging, identification of physical characteristics such as material, configuration, dimensions.	Review of OEM and OES documentation (technical manuals, drawings, test reports, etc.), information on the item and packaging measurement(s), testing, and other engineering evaluation/analysis.	Review of OEM and OES documentation (technical manuals, drawings, test reports, etc.), information on the item and packaging measurement(s), testing, other engineering evaluation/analysis, and, as applicable, prototype development and qualification testing.	Development of detailed design requirements. Review of OEM and OES documentation (technical manuals, drawings, test reports, etc.), information on the item and packaging measurement(s), testing, other engineering evaluation/analysis, and, as applicable, prototype development and qualification testing.
Typical Documentation	A technical evaluation is sufficient to document the information needed to determine that the item is the same as that provided by the OEM or made to an industry standard, and additional engineering is not needed.	An item equivalency evaluation is sufficient if the change is within the bounding technical requirements of the plant design, and installation can be done without detailed instructions.	A design equivalent change could be needed if the change is complex or at a component level and may require building a prototype to test/qualify and may require some field testing to be developed or special/additional installation instructions prepared.	A design change would be needed for complex changes at a component level and may require qualification test plans and reports, development of prototype post-installation/in situ testing, and special/ additional installation instructions prepared.

4.5 Procurement Evaluation



Description

A procurement evaluation is completed to document changes to procurement information such as description, applicable item specifications, and technical and quality requirements.

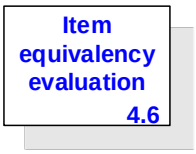
Methodology

When reverse-engineering techniques are used to recover sufficient information to procure a replacement item from an alternate supplier, a procurement evaluation should be performed to update the technical description of the item with information resulting from reverse-engineering techniques. For example, reverse-engineering techniques may be applied to identify the ASTM specification, plating, and size for a bolt that was originally purchased as a spare part for a valve and identified only with the OEM's part number. Adding enough of the recovered information (size, plating, thread-form, and specification) to the purchasing description enables the bolt to be purchased from alternate sources.

Precautions/Lessons Learned

- A procurement evaluation is typically associated with the use of reverse-engineering techniques to better describe and specify the existing design, for example, enhancing a purchasing description to enable purchase of the item from an alternate source.

4.6 Item Equivalency Evaluation



Description

An item equivalency evaluation is performed to establish that a replacement item that meets the reverse-engineering design is equivalent to the original item. Item equivalency evaluations are typically performed by procurement engineering.

Methodology

An item equivalency evaluation should be performed in accordance with licensee procedures.

Precautions/Lessons Learned

The item equivalency evaluation should not exceed the boundaries of the organization-specific procedures used (for example, some organizations do not permit procurement engineering evaluations for whole components).

4.7 Design Engineering Review



Description

A design engineering review is performed by Design Engineering to determine if the use of a proposed alternative item is within applicable bounded technical requirements.

Methodology

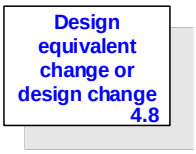
In cases when the replacement item requires it, based on criteria outlined in Steps 4.4.2 through 4.4.5, a design engineering review is performed to determine which organization-specific evaluation is appropriate (that is, item equivalency evaluation, design equivalent change, or design change).

If the design engineering review determines that a proposed alternative item is within applicable bounded technical requirements, proceed to Step 4.6 to complete an item equivalency evaluation to document the equivalency of the item. If the design engineering review determines the proposed alternative item is outside applicable bounded technical requirements, proceed to Step 4.8 to complete a design equivalent change or design change to document the acceptability of the item.

Precautions/Lessons Learned

- The design engineering review should follow the organization-specific procedures for maintaining plant configuration.

4.8 Design Equivalent Change or Design Change



Description

A design equivalent change is typically completed when involvement of individuals with design engineering qualifications is necessary to conclude that a replacement item is within the bounding technical requirements for the original item. A design change is typically completed when the replacement item is outside the bounding technical requirements for the original item.

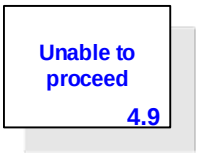
Methodology

The design equivalent change or design change process should be performed in accordance with licensee procedures.

Precautions/Lessons Learned

These processes are used to incorporate the design of the replacement into the plant's design and associated design documents (such as drawings, FSAR, design basis documents, and so forth).

4.9 Unable to Proceed



Description

Use of reverse-engineering techniques does not yield sufficient information to proceed when it is determined that it is not possible to recover enough information about an original item to identify design characteristics in sufficient detail to enable specification of a replacement. An example might be a complex circuit card with unidentifiable discrete electronic components (such as resistors, capacitors, programmable logic controllers, integrated circuits, and so forth).

Methodology

The reason that the use of reverse-engineering techniques was not successful should be documented, and other processes should be initiated to identify a suitable alternative.

Precautions/Lessons Learned

- Precautions related to the application of reverse-engineering techniques for mechanical items are included in Section 6 and in Section 7.

Steps 4.2.1–4.2.7 Sub-Process to Identify the Original Item's Design Characteristics

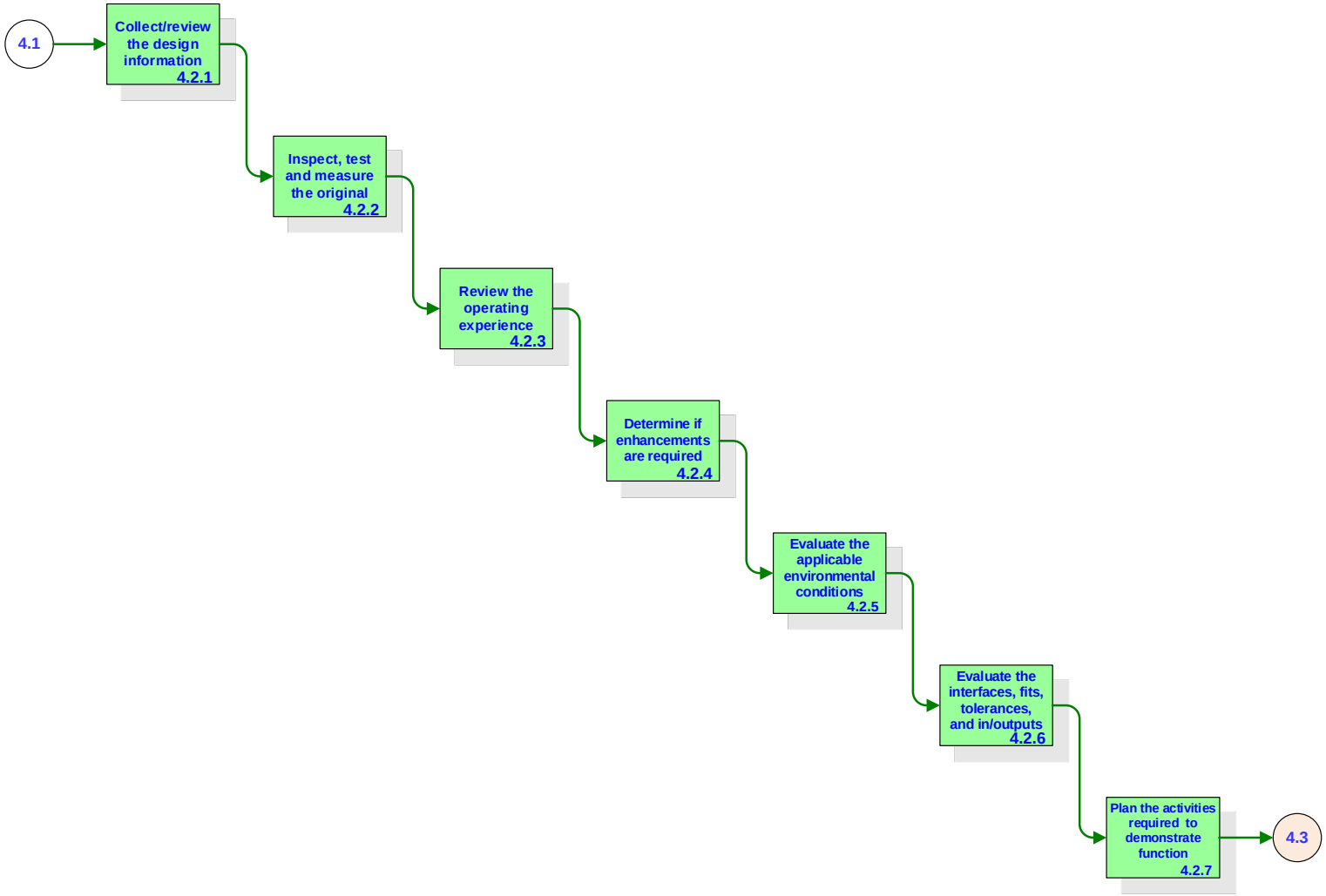
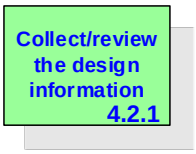


Figure 4-3
Identify the Original Item's Design Characteristics

The process depicted in Figure 4-3 is used to identify design characteristics of the original item.

Step 4.2.1: Collect and Review the Design Information



Description

This step involves gathering as much documented design information about the item being replaced as possible.

Methodology

The first step in identifying design characteristics is to collect and review available design information for the item. There are many potential sources of design information including catalogs, interface with the OEM, drawings, specifications, material codes and standards, design basis documents, and procurement documents. Additional discussion regarding the types of documents typically available is discussed in Section 5 of this report.

This information would include information associated with the item itself, as well as the technical parameters associated with the item's functions.

In general terms, the licensee typically has access to and knowledge of end-use (that is, design basis) information, whereas the OEM or a third-party organization typically has access to and knowledge of item-specific design information.

Availability of design information for an item is important as it directly relates to the potential risks, costs, and success of a reverse-engineering project. A primary source of design information is documents provided by the OEM, original equipment supplier (OES), or nuclear steam system supplier (NSSS) supplier, as applicable. When feasible, obtaining design or source control drawings from the original supplier can significantly reduce the risks, costs, and time associated with the application of reverse-engineering techniques.

Design information can be ascertained from sources that may reveal details about the item's design such as:

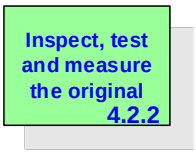
- OEM/OES drawings
- OEM/OES material certifications, for example, certified material test reports (CMTRs)
- Historical procurement documents; for example, purchase orders, receipt inspection reports, certificates of conformance/compliance, test and inspection results
- Component/item repair records
- Vendor technical manuals
- Equipment test reports, such as functional, design, Underwriter's Laboratories (UL), National Electrical Manufacturers Association (NEMA), and other such reports

- Plant maintenance history
- Original plant equipment/system specifications
- Plant design basis re-verification documents
- FSAR
- Material specifications such as ASTM, American Society of Mechanical Engineers (ASME), and so forth
- Codes and standards
- Licensee technical evaluations
- Vendor QA source inspection, surveillance, audit reports
- NRC Vendor Inspection Branch (VIB) audit reports
- NRC Inspection & Enforcement (IE) bulletins/notices
- 10CFR Part 21 [10] notifications
- Military (MIL) standards
- Maintenance procedures

Precautions/Lessons Learned

- Documents with potential design-related information should be compiled and thoroughly reviewed. Information should be assembled from multiple sources to develop an accurate, original design baseline for the item.
- It should be noted that public NRC documents such as information notices, inspection reports, and notices of violation are a good potential source of data. All pertinent information should be compiled and reviewed to determine the extent of available information. The design characteristics should serve as the finite list of information to be extracted from design documents. After the appropriate design characteristics have been ascertained through document collection and review, then the documentation collection phase is considered complete.
- The documentation review can also reveal manufacturing processes, special conditioning, and hidden design attributes that would not be readily evident. For example, manufacturers of electronic equipment sometime require two or more components to be a “matched pair” for the circuit to function properly. Because of this review, insight will be gained on any special manufacturing techniques or special attributes imposed on the item by the next higher-level assembly. Furthermore, this review may lead to the identification of standards (that is, industrial, engineering, quality, etc.) or special testing that may need to be imposed on the reverse-engineered item.

Step 4.2.2: Inspect, Test, and Measure the Original



Description

This step involves the examination of one or more specimens of the existing items being reverse engineered. In some cases, this includes an examination of equipment that interfaces with the items being reverse engineered.

Methodology

One or more specimens of the item being reverse engineered should be inspected and tested, if available.

While it may be possible to determine design functions through a top-down review of system- and component-level information, sometimes this information is incomplete or not available. In such cases, information about design functions can be inferred through examination of the original item. In such cases, an underlying assumption is made that the design of the original item was sufficient for its application, so assessing the item's design characteristics can be useful in developing the complete set of design functions.

This examination can also be used to serve as confirmation of the previously assembled data and provides any missing data. The amount of inspection and testing should be commensurate with the complexity and safety significance of the item to the extent required to ascertain whether the spare item represents the documented design data requirements.

If possible, inspection and testing should be performed on one or more unused items procured directly from the OEM/OES. This provides added assurance of the quality of the test specimen. However, it is also acceptable to perform testing on items that have been in service in the plant, noting any wear, damage, or degradation. Some data may be gleaned from items that have failed in service to ensure suitability of application.

4.2.2.1 Visual Inspection

The purpose of visual examination is to document the overall configuration of the item and identify any unique manufacturing processes. The item should be photographed, including close-ups of any special manufacturing details or areas of interest. Photographs provide a permanent visual record of the configuration and general condition of the item. A comprehensive written description of the item should complement the photographs.

The physical appearance of the item should be examined using microscopes, borescopes, and any other appropriate visual inspection tools. Such examination can assist in identifying manufacturing and/or assembly processes in the fabrication of the item. For example, an

experienced manufacturing engineer, machine designer, or machinist can determine the type of machine used to roughly shape and finish a metallic item through examination of the item's surface with a microscope. This could be further used in determining appropriate dimensional tolerances associated with the surface condition and manufacturing process.

Visual inspection may also include a walkdown of equipment installed in the plant to compare the as-built configuration with existing plant documentation. A walkdown will also help validate the operating environment, mounting configuration, and wiring and confirm that the uninstalled specimen is the same as installed equipment.

4.2.2.2 Dimensional Analysis

Dimensional analysis of the existing item is a critical area for most reverse-engineering projects. Dimensional analysis is used to satisfy the two critical parameters of fit and form. Dimensional analysis is the complete and accurate measurement of all item dimensions that are required to fully characterize the item and establish a configuration baseline. Generally, dimensional analysis is conducted using calibrated micrometers, calipers, depth gauges, thread gauges, and any other measurement tool required to ascertain the item's dimensions.

Other sophisticated technologically advanced methods of dimensional analysis include coordinate measuring machines (CMM), X-ray CT, and laser scanning. These advanced methods can expedite and enhance the accuracy of dimensional analysis. Where appropriate, advanced methods should be considered and used based upon the item's complexity and safety significance. Information about advanced reverse-engineering technologies is included in Section 9.

4.2.2.3 Functional Testing

Functional testing can be used to confirm existing data, reconcile discrepant data, and/or obtain data that are not already available through documentation reviews or inspection. Functional testing should, to the extent possible, duplicate the function of the item in service. In some instances, functional testing will reveal characteristics that may be different from those reflected on nameplates or in documentation. For example, functional testing of a power supply may reveal output voltage higher or lower than what is indicated on the nameplate.

For some items, where the component's design requirements are unknown, it might be useful to test the component to failure to determine certain design characteristics, but this really is not related to the design envelope.

Special test fixtures or jigs may have to be fabricated to support functional testing of the specimen. This may not be applicable to simple mechanical items or electrical/electronic piece parts (for example, shafts, valve stems, capacitors, resistors, coils, and other similar items).

4.2.2.4 Materials Testing and Analysis

In cases where material properties are design characteristics, it may be appropriate to perform material testing and analysis of the specimen, including the use of material identification technologies such as those identified in Table 6-1 and Table 6-2. However, some technologies may identify materials only down to the generic chemical name or "family" level.

Utilities and suppliers have invested in technologies such as FTIR to analyze and identify organic materials. This type of technology is considered adequate for most reverse-engineering uses. It is important to accurately identify these materials and be aware of their criticality in the reverse-engineering process. When using such technology, it is important to be aware of the limits and capabilities of the equipment being used.

4.2.2.5 Disassembly

Characteristics of some items may be hidden and not fully recognized until the item is disassembled. Inspection of the item may reveal unique parts that were not evident from the initial exterior examination. Even what appears to be a simple one-piece item may be assembled from many pieces.

For example, a licensee that was performing a feasibility study of advanced dimensional analysis systems supplied a spindle from a 1" X 2" water relief valve to three organizations to perform scanning of the item. The spindle was approximately 8.5" long and 0.357" in diameter with two tapered portions of 0.77" and 0.53". The spindle was simple in nature and appeared to be manufactured from a solid piece of 416 stainless steel. The item was subjected to x-ray CT, laser scanning, and contact probe scanning. All methods accurately replicated the external configuration of the spindle. However, the x-ray CT scan identified that the spindle was actually manufactured from four different pieces instead of being one solid machined piece.

Disassembly should be performed with care and precision. The process should be documented with photographs, notes, and a list characterizing each piece and the order in which the pieces were removed. As appropriate, technologies such as videography may be used in the disassembly process. Design requirements, such as torque values and spring compressions, may need to be measured and documented. Some subassemblies may be manufactured from separate components and welded, riveted, epoxied, or bonded in some other fashion. Eventually, these components may require destructive disassembly to fully evaluate their design requirements.

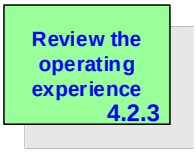
During the disassembly, a thorough understanding of the internal features and processes to manufacture the item is acquired. This knowledge is translated into an accurate assessment of the cost and time required to develop drawings and process specifications and to manufacture the reverse-engineered item.

Precautions/Lessons Learned

- Suppliers should obtain permission from the licensee when provided a specimen prior to disassembly or destructive testing.
- Destructive testing should be performed after other examinations (for example, dimensional) that require the specimen to be in its original state.
- When applying reverse-engineering techniques to environmentally qualified items, a more definitive method should be used to accurately identify organic materials beyond the “family” level of compounds. Most organic material identification methods are destructive in nature; therefore, an adequate number of known specimens must be available to use such methods.

- Purchasing descriptions for spare and replacement parts often include information related to the host component that could be misinterpreted as pertaining to the part. For example, a check valve hinge pin may be described as, “Pin, Hinge, 6” Carbon Steel, Check Valve.” In this case, the reference to size and material is most likely a reference to the valve, not the hinge pin.
- If a functional test is deemed necessary to better understand the function and fits of the replacement item, it is strongly recommended that the functional test be performed on the specimen prior to disassembly.
- A specimen is usually needed to successfully accomplish a reverse-engineering project. However, having multiple qualified and/or dedicated specimens of the same part number from different manufacturing batches helps identify equivalent components that can be used. For example, while a replacement for a certain capacitor found on one printed circuit board may be difficult to locate, additional printed circuit board specimens may reveal that a different style of capacitor, which is more readily available, was also used in the same application.

Step 4.2.3 Review the Operating Experience



Description

This step involves the review of available operating experience (OE). The types of OE available to licensees are typically different than those available to suppliers.

Methodology

OE with the item being replaced should be considered when performing reverse-engineering techniques and during the recovery of design information. Licensees should summarize and share pertinent OE with external organizations that do not have access to that information.

A review of external and internal OE related to the task to be performed should be completed to help identify any relevant details regarding the design of the item. This information should be evaluated, and a brief summary/conclusion of the applicability of the OE information should be documented as it relates to the task/evaluation being performed.

External databases available for OE research, retrieval, and analysis can include NRC Agency-wide Documents Access and Management System (ADAMS) database (nrc.gov), various internet-based search engines, and other databases containing industry-wide data. Searching on the device type, OEM name, description, and part and model number may yield useful information.

Internal sources of plant-specific OE of the item being replaced can include supplier databases and licensee-specific corrective action program data; and the following parameters should be considered:

- Replacement frequency of the item
- Required maintenance of the item
- Mean time between repairs (MTBR)
- Mean time between failures (MTBF)
- Reliability of the item

The following are the possible outcomes resulting from an OE search and evaluation:

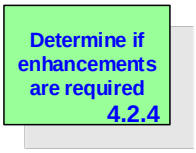
- Possible identification of an adverse condition
- Possible identification of a gap that needs to be corrected by incorporating enhancements into the replacement item's design
- Possible identification of the need for additional discipline/licensee specific reviews and/or engineering controls (for example, preventive maintenance activities, etc.)
- Opportunities to enhance the replacement item to increase design margin
- No action is required if identified OE is evaluated as not-applicable to the current activity

In summary, both internal and external OE information should be considered and shared.

Precautions/Lessons Learned

- Valuable operating experience can be obtained through interviews with system engineers, maintenance personnel, and other technicians. However, care should be taken to validate this type of operating experience.

Step 4.2.4 Determine If Enhancements Are Required



Description

This step involves evaluating information that suggests enhancements to the replacement item's design are needed and ensuring that proposed enhancements are compatible with the item's design functions.

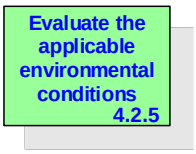
Methodology

After evaluating OE associated with the item being replaced, experience indicating poor performance or an inadequate/obsolete design may indicate that enhancements to the replacement item may be warranted.

Precautions/Lessons Learned

- In addition to OE, there are other reasons why the design of the item may be enhanced (for example, new materials, new technologies, new fabrication techniques, weaknesses with the original design, enhancements to facilitate maintenance and testing, and so forth).
- Enhancements that improve and change the original design characteristics may require additional engineering evaluation best accomplished in design equivalent change or design change (Step 4.8).

Step 4.2.5: Evaluate the Applicable Environmental Conditions



Description

This step includes evaluating the environmental conditions such as temperature, pressure, humidity, radiation, chemical spray, seismic demand, EMI/RFI, and vibration that can impact the ability of the item to perform its design function.

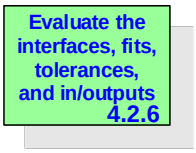
Methodology

In most cases, the licensee can evaluate environmental conditions using existing documentation. However, in cases where environmental data are not available, the conditions can be determined through measurement or calculation. The results of the evaluation of environmental conditions should be documented and incorporated into reverse-engineering outputs.

Precautions/Lessons Learned

- When available, licensees should provide environmental information to the supplier supporting the reverse-engineering techniques.
- When using technologies such as FTIR, consider the capabilities of the test equipment, such as whether the equipment is sufficiently sensitive to detect changes in organic materials that might impact previous qualification testing.

Step 4.2.6: Evaluate the Interfaces, Fits, Tolerances, Inputs, and Outputs



Description

This step includes evaluating various characteristics that impact the ability of the item to perform its design functions. These characteristics relate to how the item interacts with its interfacing host component/system and how some internal parts interact with each other as necessary to perform the item's design functions.

Methodology

One key to the overall analysis is the evaluation of the item in relation to its fit, form, and function within the next-higher assembly and the overall system, as applicable. This assists in determining the item's fits, tolerances, inputs, outputs, required accuracy, etc. Item interfaces should be carefully examined and documented to ensure proper part function within the host equipment.

Dimensions should be bounded by appropriate tolerances. Many variables play critical roles in the determination of fits and tolerances, including:

- Function of the item
- Type of manufacturing process
- Mating of parts
- Types of fits (clearance, interference, etc.)

All of these variables can be combined with various weighting factors to establish the correct tolerances in the original design. There are some published standards, such as those of the American Bearing Manufacturers Association (ABMA), for fits and tolerances for bearing to shaft fits. See Section 8 for a listing of standards related to fits, establishing dimensions, and tolerances. However, the application of such standards is up to the individual designer.

Unfortunately, the organization performing reverse-engineering techniques typically does not know what combinations of variables were used by a designer on a particular day establishing tolerances for a particular item. This places those performing reverse engineering at an extreme disadvantage. Generally, good engineering judgment and criticality of the item combined with the manufacturing process should dictate the prescribed fits and tolerances.

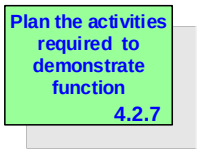
Although no method provides absolute assurance that the reverse-engineered item's fits and tolerances are the same as the original item, there are many technically sound methods and criteria for establishing fits and tolerances of reverse-engineered items. The item's safety significance should be considered when establishing fits and tolerances. Section 6 of this report provides more detailed guidance for establishing mechanical and electrical tolerances.

Precautions/Lessons Learned

- When reverse engineering a single component of an entire system, it is important to consider the integrity of the inputs to the reverse-engineered replacement component (that is, interface requirements). Interfacing contacts, pins, or terminals may degrade over time in the system and reverse-engineering techniques may not accurately capture such degradation, causing potential spurious actuation of a duplicate component when placed in service.

- In selecting the prototype location to field fit a replacement, care should be taken to ensure that the location is representative of other locations where the replacement is suitable to use.
- Field verification is sometimes warranted on each replacement item to validate the assumptions made regarding fits and tolerances. For example, there may be differences in the alignment of contacts that cannot be reasonably detected through engineering analysis.
- Appropriate verification methods should be selected to confirm fits and tolerances that are critical to the ability of a device to function correctly.

Step 4.2.7: Plan the Activities Required to Demonstrate Function



Description

This step includes planning activities that will demonstrate that the replacement item meets the specified requirements and will perform its design functions.

Methodology

The functionality of an item is typically demonstrated by methods such as inspection, testing, and engineering analysis. Demonstrating the functionality of a replacement item designed and manufactured based on application of reverse-engineering techniques should include consideration of application requirements, plant licensing basis, interfaces, and operating environment. In some cases, it may be necessary to develop a test fixture to demonstrate the item's ability to interface correctly with the host or parent SSC. Expertise in manufacturing, testing, or operating the type of item may be required to plan activities that effectively demonstrate its function. When applicable, expertise in equipment qualification (seismic, environmental, EMI, RFI, and so forth) may also be required.

Documentation necessary for successful procurement or manufacture of the item should be developed and used as input for planning activities to demonstrate function. This information can then be adjusted, as necessary, and used to control the design of items after they successfully demonstrate the ability to perform their functions. This type of documentation may include:

- General description
- Physical requirements
- Electrical requirements (as applicable)
- In situ conditions (temperature, humidity, radiation, etc.)
- Documentation requirements
- Quality assurance requirements
- Qualification testing requirements (seismic, environmental, EMI, RFI)

More complex items may require development of additional design and manufacturing information to communicate aspects of the item's design such as:

- Drawings
- Schematics
- Bill of materials
- Mechanical (packaging) design
- Assembly procedures
- Test fixture design
- Test equipment requirements
- Qualification testing plan and procedure
- Production test procedure

When equipment qualification or conditioning is required, qualification testing of either a prototype, first-article, or production version of the reverse-engineered item may be necessary to demonstrate the item's functionality during and after a design basis event. When a first article or prototype is used for qualification testing, any difference between it and the production version shall be analyzed for its effect on qualification and documented in an engineering evaluation. Typical types of qualification testing or conditioning include:

- Environmental
- Seismic
- Electromagnetic or radio-frequency compatibility (EMI/RFI)
- Radiation exposure
- Thermal aging
- Operational cycling

Assessment to determine adequacy of design can be performed in parallel with or following qualification testing.

In cases where testing is required to establish functionality, it may be necessary to develop a prototype of the item. Testing of a prototype can provide evidence that an item produced from a reverse-engineered design is capable of performing its intended functions. In some cases, a prototype may be a partially built item that reflects certain aspects of the design of the new item to enable specialized testing. For example, when reverse engineering an electric motor, testing of a formette (form wound) or motorette (random wound) might be performed to demonstrate the suitability of a new motor insulation system prior to manufacturing a complete motor.

Engineering analysis performed as part of the qualification or reverse-engineering process can also be used as input for planning activities to demonstrate function. This type of documentation may include:

- Similarity analysis
- Reliability calculations

- Uncertainty calculations
- MTBF/MTBR calculations

Precautions/Lessons Learned

- Care should be used when using OEM acceptance testing procedures as a basis for acceptance because the OEM acceptance criteria may not envelope end-use design requirements.
- It is imperative that the customer provides all available documentation and procedures available, including calibration and testing procedures. It is important that procurement and supply chain personnel fully engage engineering organizations during the implementation of reverse-engineering techniques.
- It may be necessary to obtain information related to actual in situ conditions (for example, overvoltage and undervoltage) when planning tests to verify function. If assumptions are made in the absence of this information (for example, the reverse-engineered design and associated testing are based upon ratings included in original nameplate data), the assumptions should be included, as appropriate, in documentation such as certification.

Steps 4.3.1–4.3.11 Sub-Process to Establish/Vet Replacement Item Design

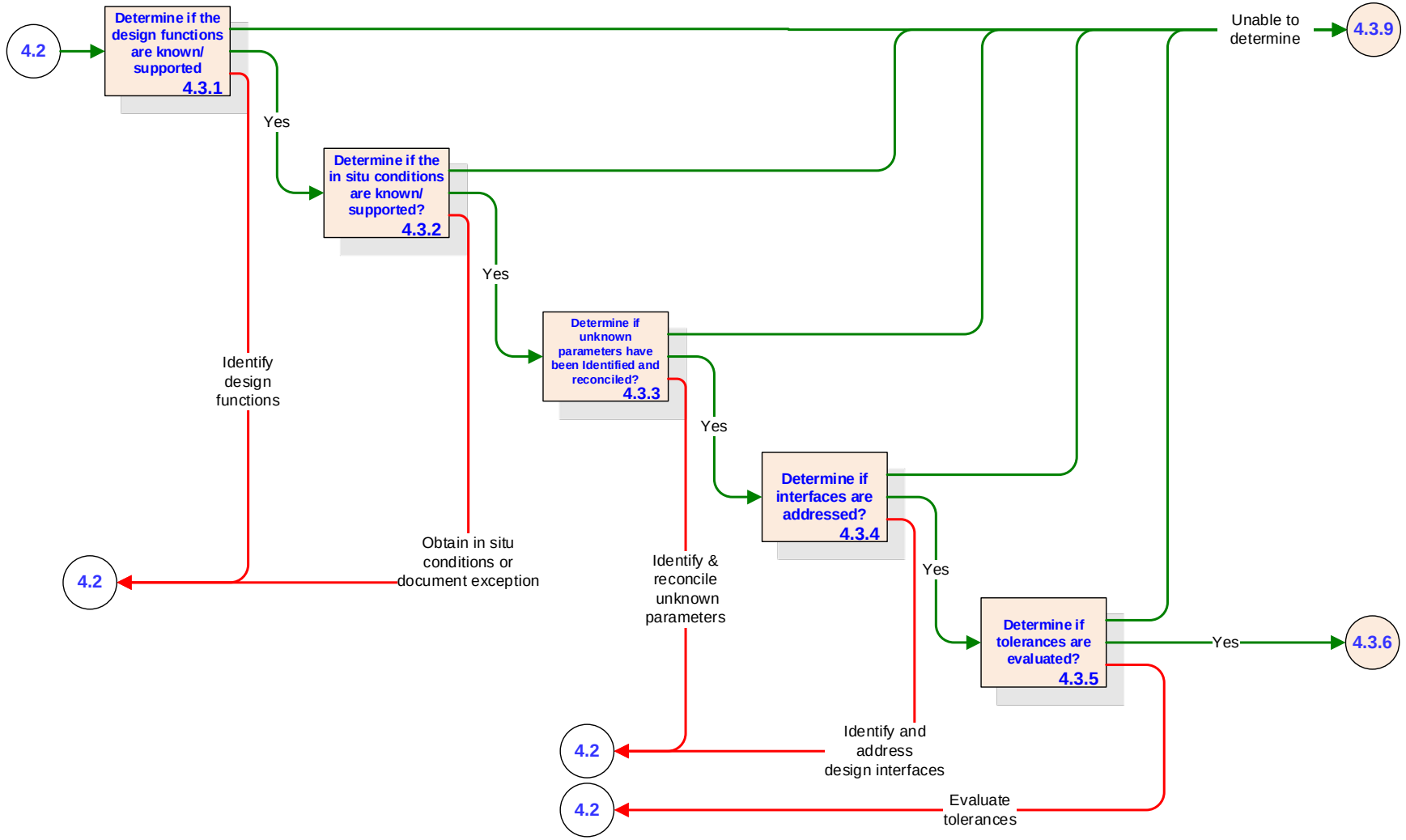


Figure 4-4
Establish/Vet Replacement Item Design, page 1 of 2

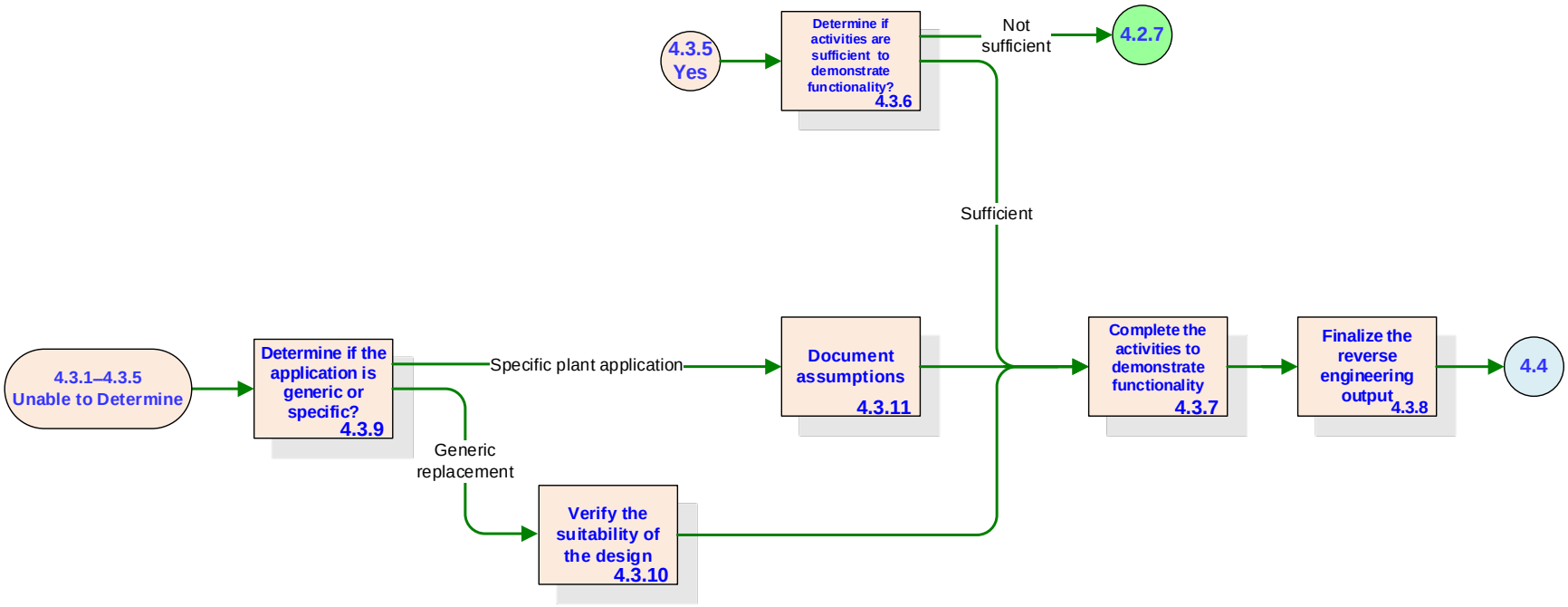
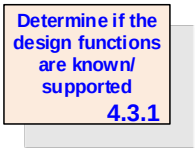


Figure 4-5
Establish/Vet Replacement Item Design, page 2 of 2

Step 4.3.1: Determine If the Design Functions Are Known/Supported



Description

This step involves reviewing the information recovered using reverse-engineering techniques to verify that the design functions of the item are identified and that the design characteristics identified will ensure that the item can perform its design function(s).

The design functions of the item (both safety and non-safety) should be assessed. Consideration should be given to the role that the reverse-engineered item plays with respect to the higher-level system or component in which it will be installed. A qualitative description of what functions that item needs to perform should be documented. For example, a valve stem for a motor-operated valve needs to transfer a specific amount of thrust from the stem nut to the valve disc. A circuit card used to control a motor must be able to supply sufficient field and stator currents to operate the motor under a predetermined range of conditions.

Methodology

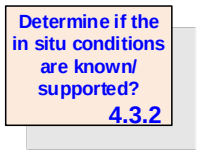
In the absence of original design and manufacturing information, it is essential to know what the item's functions are and to review design characteristics recovered via reverse-engineering techniques to ensure that the characteristics will enable the item to perform its intended functions.

If plant design functions are known and supported by the replacement item design, proceed to Step 4.3.2. If unable to reconcile unknown information, there are two possible options. The first is to return to Steps 4.2.1 through 4.2.7 and attempt to recover the missing information. The second option is to proceed to Step 4.3.9 to define the intended application(s) and plant design functions of the item and document assumptions associated with the identified applications.

Precautions/Lessons Learned

- Communication between the reverse-engineering entity and licensee personnel familiar with operating principles of the equipment/item may be helpful to ensure that all design functions are known and supported.
- A simple FMEA may be an effective tool for determining that the design characteristics are sufficient to demonstrate that the design functions are supported.

Step 4.3.2: Determine If the In Situ Conditions Are Known/Supported



Description

This step involves determining if the actual in situ conditions have been determined and incorporated into the replacement item specification.

Methodology

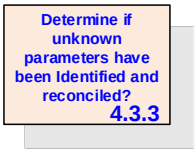
The purpose of this review is to determine if conditions to which plant equipment may be sensitive, such as room temperatures, chemical spray, and radiation (that can potentially impact the item's ability to function correctly), are adequately addressed.

If in situ conditions are known and are supported by the replacement item design, proceed to Step 4.3.3. If in situ conditions are not known or are not supported by the replacement item design, there are two possible options. The first is to return to Steps 4.2.1 through 4.2.7 and attempt to determine and account for in situ conditions. The second option is to proceed to Step 4.3.9 to document the in situ conditions for which the replacement item design is intended and to document assumptions made in the absence of in situ condition information for a specific application.

Precautions/Lessons Learned

- Additional temperature effects due to self-heating of the item or surrounding items is an in situ condition that should be considered.
- Suppliers implementing reverse-engineering techniques may not always be provided with detailed information related to in situ conditions. Therefore, the supplier should obtain confirmation from the customer that in situ conditions have been addressed and communicated.

Step 4.3.3: Determine If Unknown Parameters Have Been Identified and Reconciled



Description

This step involves identifying and documenting any remaining unknown information about the item, its application(s), and in situ conditions and determining if unknowns have been sufficiently reconciled and communicated to the customer.

Methodology

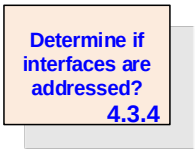
Identification of unknowns involves a critical review of information that has been recovered to determine if any necessary information associated with the item's design characteristics or end-use application remains unknown. Reasons that this information might remain unknown might be, for example, an inability to recover an important design characteristic because destructive examination was not an option or because a functioning specimen was not available to evaluate. An example of unknown information about the application might be actual in situ conditions such as current or voltage.

Proceed with Step 4.3.4 if there are no unknown parameters or information, if the unknown information has been identified and reconciled, or if provisions for obtaining the unknown information are included in activities to demonstrate functionality (Step 4.3.7). If unable to reconcile unknown information, there are two possible options. The first is to return to Steps 4.2.1 through 4.2.7 and attempt to recover the missing information. The second option is to proceed to Step 4.3.9 to determine intended application(s) for the item and document assumptions made in the absence of certain information.

Precautions/Lessons Learned

- As the complexity of the item increases, the probability of needing to reconcile unknown information typically increases.

Step 4.3.4: Determine If Interfaces Are Addressed



Description

This step involves determining if applicable interfaces have been identified and evaluated.

Methodology

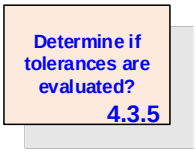
For electrical items, this would typically involve evaluating inputs and outputs, physical configuration, and mounting, as well as ensuring that the equipment is configured correctly (for example, dip switches, jumpers, and so forth). For mechanical items, this would typically involve evaluating linkages, physical connections, clearances and fits, wear surfaces, mating surfaces, material, compatibility, and mounting.

If interfaces have been identified and evaluated or provisions for identifying and evaluating interfaces are included in activities to demonstrate functionality (Step 4.3.7), proceed with Step 4.3.5. If unable to obtain interface information, there are two possible options. The first is to return to Steps 4.2.1 through 4.2.7 and attempt to recover the missing information. The second option is to proceed to Step 4.3.9, to determine the intended application(s) for the item and document assumptions made in the absence of identification and evaluation of interfaces.

Precautions/Lessons Learned

- When applying reverse-engineering techniques to an item, risk can be reduced by considering what interfacing equipment requires the item to do. For example, if a motor controller is being reverse engineered, consider the amperage demanded by the motor (starting or running current), in addition to examination of the original motor controller itself. For example, the reverse-engineered motor controller might need to be capable of providing amperage demanded by the motor in various design conditions, and these design conditions may not be evident from examining only the motor controller.

Step 4.3.5: Determine If Tolerances Are Evaluated



Description

This step involves evaluating tolerances associated with or established for both mechanical and electrical attributes.

Methodology

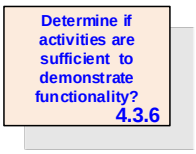
For mechanical items, this involves determining if tolerances associated with critical fits are appropriate for each specific application and feature type. Detailed information for establishing tolerances is provided in Section 8 of this report. For electrical items, this could involve establishing and/or evaluating the aggregate tolerances of electric circuits such as resistance, capacitance, input-output voltage, and so forth.

If tolerances have been evaluated or provisions for identifying and evaluating interfaces are included in activities to demonstrate functionality (Step 4.3.7), proceed with Step 4.3.6. If tolerances have not been adequately evaluated, there are two possible options. The first is to return to Steps 4.2.1 through 4.2.7 and attempt to recover or establish the missing information. The second option is to proceed to Step 4.3.9.

Precautions/Lessons Learned

- When establishing tolerances, include consideration of environmental factors such as temperature that can adversely impact fit, function, and interfaces.
- Taking measurements at multiple locations on a single specimen can provide insight into tolerances based on the variations among the data points taken.
- Dimensions and tolerances based on measurement of used items should include consideration for wear and deformation that might have resulted from previous use.
- Additional information on establishing tolerances is included in Section 8 of this report.

Step 4.3.6: Determine If Activities Are Sufficient to Demonstrate Functionality



Description

This step involves determining if sufficient activities to demonstrate functionality were established in Step 4.2.7. Establishing functionality may involve fabrication and testing of a prototype to establish suitability of design. Testing might include:

- Functional testing
- Seismic/environmental qualification testing
- EMI/RFI qualification testing
- Verification and validation of computer programs

Methodology

Considering what is known about the item and its intended application, determine if the activities planned to demonstrate functionality of the item are sufficient to establish that the replacement conforms to the design documents and will perform its design function(s). The activities should be commensurate with the item's complexity and safety significance and of sufficient detail to establish that the reverse-engineered item meets the design requirements of the design documents and will perform its intended function(s).

Examination by Maintenance Technicians

To reduce the probability of future issues with fit and function of the replacement part in the field, the reverse-engineered replacement can be sent to the plant's maintenance team for a thorough review and inspection by knowledgeable technicians. This review and inspection may help determine if any aspects of the item are not in line with current plant requirements. Some typical activities used to demonstrate functionality are the following:

In Situ Testing

It may also be necessary to perform in situ testing of a prototype reverse-engineered item before final production. Depending on location in the plant and planned outage schedules, it may be possible to install the prototype replacement item in the actual end use location to ensure proper function and fit. As an alternative to in situ testing, the mating components for the item being reverse engineered can be sent to the supplier performing reverse engineering for fit-up testing by the vendor.

First Article Examination

Although more complex items such as assemblies with critical safety functions may require testing to ensure that performance requirements are met, first article review is a method available to verify the suitability of relatively simple reverse-engineered items. First article review involves performing a side-by-side comparison of a reverse-engineered item and an existing (and suitable) OEM item currently installed or in stock.

For example, consider a hinge pin that is reverse-engineered in accordance with design documents approved by the end user. Production of the hinge pin proceeds in accordance with the drawing and supporting quality requirements. The starting material is verified via approved material supplier test records or through testing per the standards referenced in the reverse-engineering documentation. This may include chemical and mechanical testing to verify material and condition. The production process begins after material is verified.

Typically, the first item from the production line is inspected for conformance with the drawing prior to proceeding with the manufacturing of additional items. This inspection ensures that dimensional characteristics are within the tolerances specified on the drawing. In some cases, first article examination may occur during various steps in the manufacturing process.

Prototype Development and Testing

If the purpose of the reverse-engineering effort is to manufacture or fabricate an item, it may be appropriate to develop and test a prototype specimen. For items that are relatively simple in nature, a prototype may not be required.

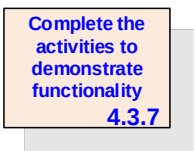
Independent testing laboratories and facilities may be needed in some cases to test prototypes.

If the prototype does not pass testing, then a failure analysis of the prototype may be required to determine the root cause and incorporate appropriate design changes. Methods of testing may also require examination to ensure that prototype testing was appropriate and was not the root cause of the failure. If the prototype passes testing, then there should be a relatively high level of confidence that the item will perform as required in service.

Precautions/Lessons Learned

- Consideration should be given to developing a matrix such as the format included in Appendix B, which maps each of the design characteristics identified in Steps 4.2.1 through 4.2.7 to a specific verification method. This is particularly important for complex items.

Step 4.3.7: Complete the Activities to Demonstrate Functionality



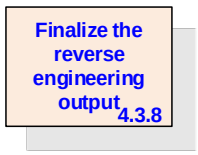
Description

This step involves conducting the activities necessary to demonstrate functionality that were planned in Step 4.2.7 and determined to be sufficient in Step 4.3.6. These could include inspection, testing, prototype development, qualification testing, and so forth.

Methodology

Execute the activities that were planned to demonstrate functionality in Step 4.2.7. Appropriate investigation and action should be taken if any of the planned activities fail to meet acceptance criteria (for example, review of assumptions, design review, test procedure revision, and so forth).

Step 4.3.8: Finalize the Reverse-Engineering Output



Description

After activities to demonstrate functionality of the design are successfully completed, documentation necessary to purchase or manufacture the item is finalized to reflect the approved design. Finalizing reverse-engineering output involves completing the specification for the replacement item. For the purposes of this report, a specification comprises existing design input resulting from reverse-engineering techniques that includes performance requirements, parameters, and other information sufficient to provide a replacement item that will perform its design basis function(s). This information is typically included in procurement documents or manufacturing information for the replacement item and may be supplemented with supplier quality and documentation requirements in some cases.

For items manufactured in accordance with industry standards, such as a fastener, the output may be as simple as an enhanced description for use in future procurement documents. For simple items, such as machined replacement parts, the output may consist of fabrication drawings and manufacturing information. For more complex items such as components, output may include bills of material, qualification test records and results, component-level specifications, and other pertinent information.

Methodology

Developing this information may result in drawings, specifications, manufacturing process sheets, bill of materials, test procedures, or any other documentation commensurate with the intended purpose of the information. For the purposes of this report, the collective assembly of this information is referred to as *reverse-engineering output*. Finalized reverse-engineering output should reflect the final, approved design of the item and provide objective evidence that the reverse-engineered item is capable of performing its intended functions.

A summary report similar to the one included in Appendix C may be provided for complex reverse-engineering projects.

Any drawing, specification, procedure, or other document generated via reverse-engineering techniques that affects the item's design basis should be reviewed and approved in accordance with the licensee's quality assurance program.

Fabrication or manufacturing drawings and specifications developed for the reverse-engineered item must be in sufficient detail to allow manufacture of the item. This includes delineation of:

- Materials of construction
- Dimensions
- Tolerances
- Surface finishes
- Special conditioning (heat treatment, burn-in, etc.)
- Special processes such as welding, soldering, nondestructive examination (NDE) and so forth
- Bills of material
- Wiring diagrams
- Schematic drawings
- Logic diagrams

Development of specifications and drawings can be a complex process that involves working with the proposed manufacturing facility. Development of manufacturing drawings is an iterative process. Development, review, and approval of manufacturing drawings should follow the reverse-engineering entity's existing procedures for drawing development and control. In manufacturing an item, the licensee may rely upon the manufacturer's established process for creation of manufacturing drawings. However, the licensee should conduct a final review and approval of the drawings.

When applicable, documentation related to equipment qualification should be included, such as:

- Qualification test reports
- Similarity and other engineering analysis related to qualification

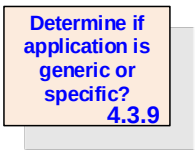
Other documentation such as the following should also be included when appropriate:

- Instruction manual
- QA data package
- Other engineering evaluations

Precautions/Lessons Learned

- A review should be conducted to verify that the reverse-engineering output addresses applicable contractual requirements.
- Procurement documents should include provisions to ensure that reverse-engineering output provided to the licensee is of sufficient detail to facilitate the fabrication of a replacement item by a manufacturer with appropriate capabilities in the future.

Step 4.3.9: Determine if the Application is Generic or Specific



Description

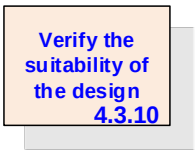
This step is the first step in defining the intended applications and assumptions made about the capabilities of a reverse-engineered item for which certain design considerations could not be established in Steps 4.3.1 through 4.3.5. This step involves determining if the replacement item will be designed for use as a generic replacement item that is associated with a certain original item or plant function. For example, a supplier applied reverse-engineering techniques to establish design information used to fabricate a replacement component for a single nuclear facility. The replacement design was based on a specimen, design information, design requirements, and interface requirements provided by the nuclear facility. After a successful outcome, the reverse-engineering entity decides to offer the component as a replacement option to other customers and facilities that need to replace the same type of component.

Methodology

If the replacement item will be marketed or used as a generic replacement, a product specification or data sheet should be prepared to communicate the design parameters for the item. These might include size, design temperatures, pressures, electrical ratings, and so forth. This data sheet can be furnished to potential users for use in determining if the replacement is suitable for their intended application.

If the replacement item is intended for use in a specific plant application, assumptions incorporated into the recovered design information should be documented so they may be evaluated by appropriate technical personnel and available for future use, as needed, to support failure investigations or future efforts to use reverse-engineering techniques.

Step 4.3.10: Verify the Suitability of the Design



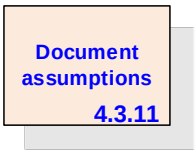
Description

This step involves verifying the suitability of the design for an intended application. This is necessary when the process of vetting the design recovered via reverse-engineering techniques reveals that one or more aspects of the design (Steps 4.3.1 through 4.3.5) could not be recovered.

Methodology

In such cases, the suitability of the design should be established using techniques such as performance of design reviews, use of alternate or simplified calculations, or performance of suitable testing (reference 10CFR50, Appendix B Criterion III [4]). In some cases, it may be practical to complete design verification activities in conjunction with completion of activities to demonstrate functionality in Step 4.3.7.

Step 4.3.11: Document Assumptions



Description

This step involves documenting any assumptions incorporated into the recovered design information so they may be evaluated by appropriate technical personnel and available for future use as needed to support failure investigations or future efforts to use reverse-engineering techniques.

Methodology

Review information gathered during identification of the item's original design characteristics and capture any assumptions made about ratings, tolerances, in situ conditions, and so forth. Document any assumptions made during completion of the replacement item design. Assumptions might be related to intended design functions, in situ conditions, interface requirements, tolerances, and so forth.

Precautions/Lessons Learned

- Document assumptions in design documents and certification, as appropriate.
- Assumptions made by suppliers should be communicated to and discussed with licensees as soon as practical.
- Undocumented assumptions cannot be verified by a reviewer to be acceptable, which could lead to a fatal design flaw.

Steps 4.4.1–4.4.8 Sub-Process to Determine Design Control Activity

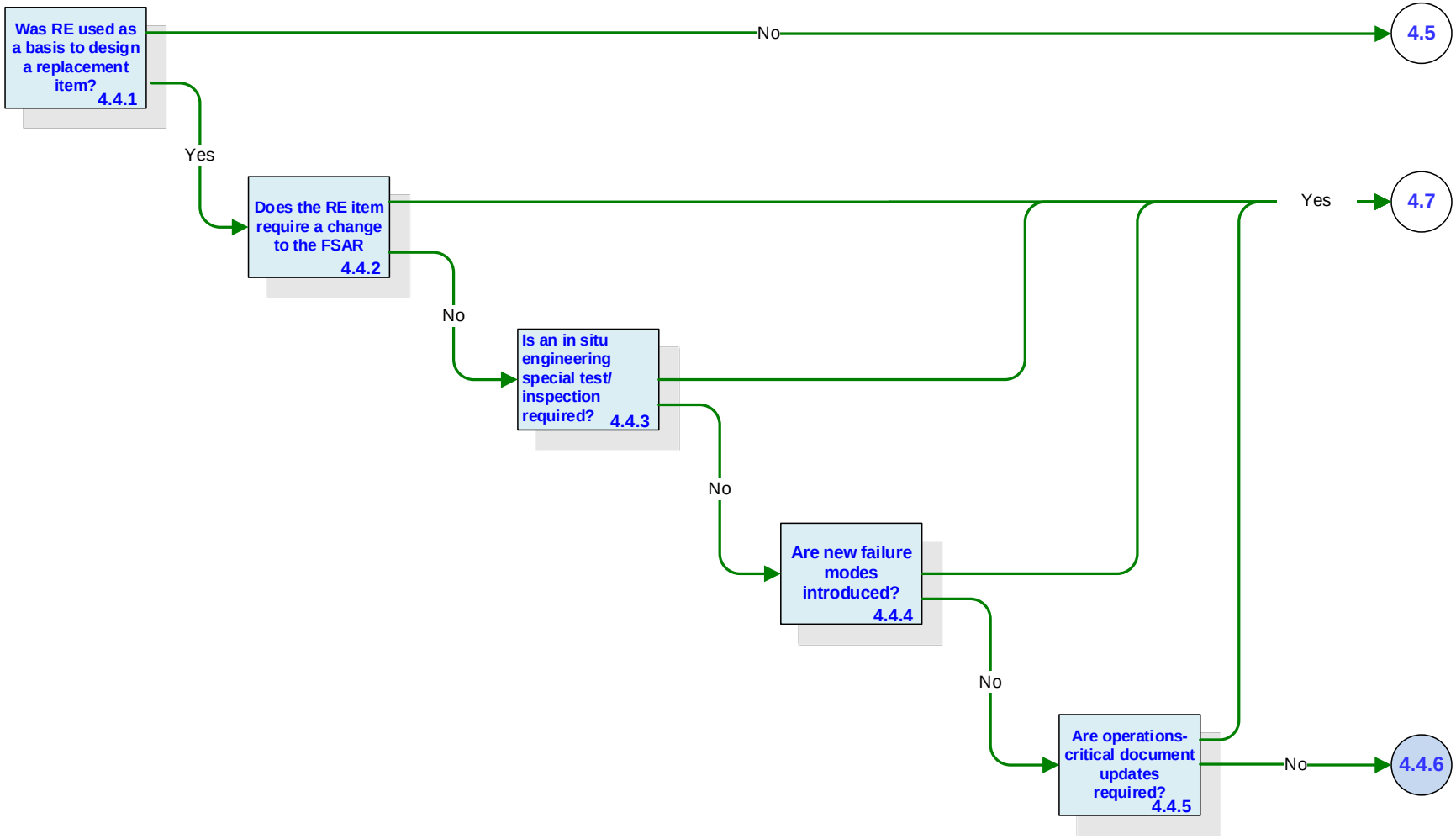


Figure 4-6
Determine the Design Control Activity, page 1 of 2

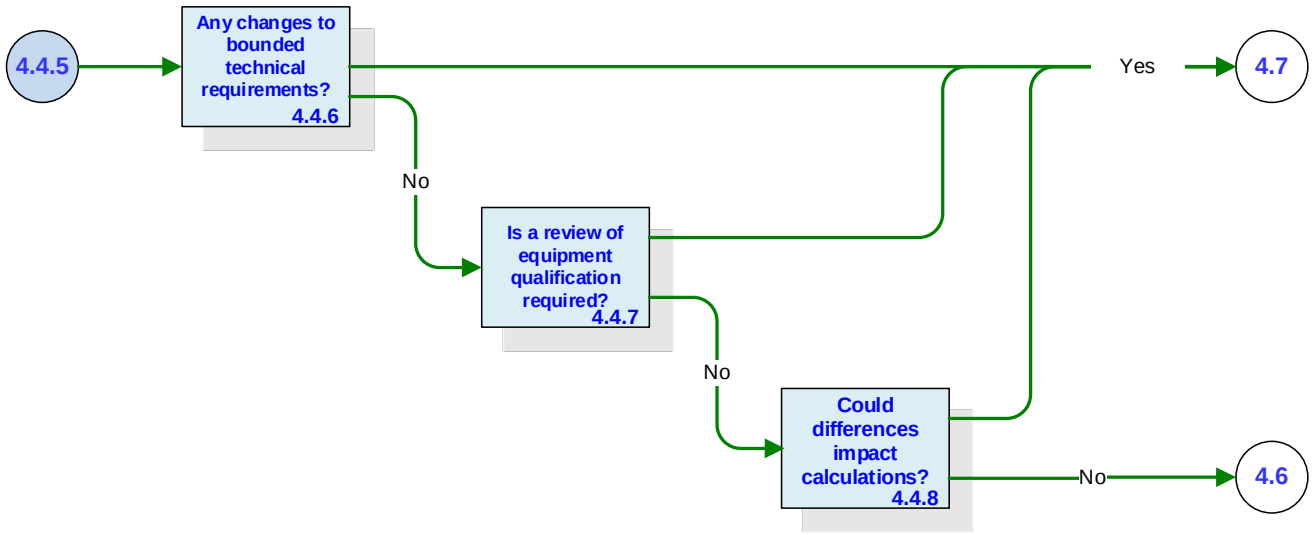
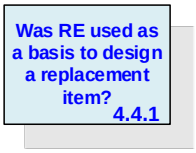


Figure 4-7
Determine the Design Control Activity, page 2 of 2

Each step or screening question in the Determine Design Control Activity sub-process (Steps 4.4.1–4.4.8) must be completed or answered. Each step or screening question that leads to Step 4.7 should be addressed in the design engineering review. There may be more than one design consideration that needs to be addressed in a design engineering review. For example, if an item requires a change to the FSAR and also introduces new failure modes, both the FSAR change and the new failure modes would be addressed in the design engineering review.

Step 4.4.1: Was reverse engineering (RE) used as a basis to design a replacement item?



Description

This step involves determining if reverse-engineering techniques were used to design a replacement item or to simply recover enough information about an item to improve the procurement description to enable acquisition from an alternate source.

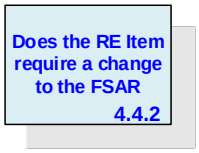
Methodology

If reverse-engineering techniques were used to recover sufficient information to procure a replacement item from an alternate supplier, then a procurement evaluation would be required as described in Section 5.2 of this report. In this scenario, the intent of reverse-engineering techniques was not to recover enough information to fabricate a replacement. For example, reverse-engineering techniques are used to identify the material specification associated with a fastener used on an obsolete component so that a replacement can be purchased from an alternate source of supply.

When reverse-engineering techniques are used to aid in identification or to confirm the design of the original item for the purposes of specifying alternate sources of supply, then the licensee should update their inventory and purchasing descriptions. Alternate items that conform to the same industry design and standards as the original item, including materials of construction, do not typically require a change process to implement and can be processed via the procurement evaluation process.

If reverse-engineering techniques were not applied to design a replacement item, but simply to enable procurement of the same item from an alternative source, proceed to Step 4.5, Procurement evaluation. If reverse-engineering techniques were used to design a replacement item, continue to Step 4.4.2.

Step 4.4.2: Does the reverse-engineered item require a change to the Final Safety Analysis Report (FSAR)



Description

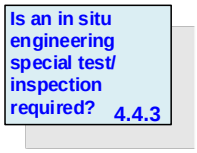
This step involves determining if the facility's FSAR needs to be updated to accommodate use of the reverse-engineered replacement item.

Methodology

If the replacement item alters a function of a design characteristic described in the operating license documentation, a license change approval may be required prior to installation, and design should be controlled using the design equivalent change or design change process. However, if the change in a particular characteristic described in licensing documents is determined to be administrative or cosmetic in nature, such as color or part number, then licensees should refer the change to their site licensing organization and configuration management process to further screen the item into the appropriate change control activity.

If updates to the FSAR may be required to accommodate use of the reverse-engineered replacement item, proceed to Step 4.7, Design engineering review. If FSAR updates are not required, continue to Step 4.4.3.

Step 4.4.3: Is an in situ engineering special test or inspection required?



Description

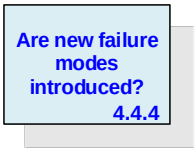
Determine if use of the replacement item requires special engineering tests, inspections, or experiments after the item is installed. Typically, these activities are conducted to establish characteristics or values not previously known.

Methodology

If the principal means of validation or verification of a reverse-engineered item's ability to support its design basis functions requires installation of the item within the boundary of the operating plant, then use of the design equivalent change or design change process should be considered to control operating conditions to mitigate and control risk. This may include items in which system interactions or performance operating tolerances cannot be easily replicated for the item using test equipment and mockups.

If in situ engineering special tests or inspections will be required, proceed to Step 4.7, Design engineering review. If in situ engineering special tests or inspections will be not be necessary, continue to Step 4.4.4.

Step 4.4.4: Are new failure modes introduced?



Description

Determine if the reverse-engineered design introduces new failure modes.

Methodology

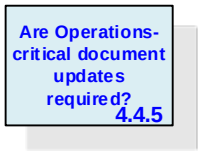
Determine if the reverse-engineered item has the potential to introduce a new failure mode or the potential for a different response to failure of other portions of the system. If the potential to introduce a new failure mode exists, then a 10CFR50.59 [11] activity screening is appropriate; and the replacement cannot be considered as an equivalent item without appropriate design engineering review.

If the reverse-engineered replacement item introduces new failure modes, proceed to Step 4.7, Design engineering review. If the reverse-engineered replacement item does not introduce new failure modes, continue to Step 4.4.5.

Precautions/Lessons Learned

- Special attention should be directed to any new characteristics or design features, resolution of unknown characteristics, firmware or software revisions, and changes from analog to digital circuits or imbedded subcomponents. Without proper review, these types of changes can introduce new vulnerabilities and failure modes such as susceptibility to EMI, RFI, or unanticipated behavior in fault conditions.

Step 4.4.5: Are Operations-critical document updates required?



Description

This step involves determining if use of the proposed replacement item would require changes to documents that are critical to plant operation, typically referred to as Operations-critical documents (OCD).

Methodology

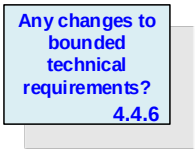
If installation of the reverse-engineered item requires that documents be updated prior to turnover of the replacement to Operations as part of the Operations activity checklist (OAC) process, then the licensee should consider use of a design equivalent change or design change for control of the required updates. These documents would be necessary to align and place the system into operation, remove the system from service, respond to trouble with or troubleshoot with the modified system/component, or to respond to an accident in which the system is needed. Typical examples of OCDs may include any of the following:

- Operating procedures
- Maintenance procedures
- One-line or logic diagrams
- Operating curves
- Calculations that specify or support operating procedures, station software, and emergency or security procedures

In some situations, training may be considered an Operations-critical activity at the time of turnover. Typically, these documents should be updated at a frequency shorter than a routine 90-day update. Licensees that have the capability to update OCDs automatically as part of the equivalency evaluation process (for example, by using the work order process) may be able to manage replacements that require OCDs using their equivalency evaluation process.

If Operations-critical updates are required to accommodate use of the reverse-engineered replacement item, proceed to Step 4.7, Design Engineering review. If Operations-critical updates are not required to accommodate use of the reverse-engineered replacement item, continue to Step 4.4.6.

Step 4.4.6: Any Changes to Bounded Technical Requirements?



Description

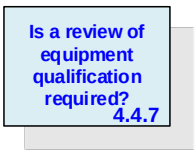
If the change represented by the reverse-engineered item results in a condition or use of a device that is outside of technical requirements (such as reduction in operating temperature; pressure; range; uncertainty or accuracy under normal, abnormal, or accident conditions), the reverse-engineered item cannot be considered as an equivalent replacement item.

Methodology

Review the original equipment specifications, system design basis documentation, impacts of other system modifications, and set-point documents to ensure that the design requirements are fully understood and met by the reverse-engineered replacement item. This activity should be carefully explored and integrated at the onset of the reverse-engineering project, with involvement from the design and system engineering organizations.

If use of the reverse-engineered item involves changes that are outside of bounded technical requirements, proceed to Step 4.7, Design Engineering review. If use of the reverse-engineered item does not involve changes that are outside of bounded technical requirements, proceed to Step 4.4.7.

Step 4.4.7: Is a Review of Equipment Qualification Required?



Description

Determine if a review of (or new) qualification activities such as seismic, environmental, or EMI/RFI testing is required to establish or maintain suitability of design for the replacement item.

Methodology

If the reverse-engineered item requires new or additional equipment qualification (seismic, environmental, EMI/RFI, etc.) to maintain or demonstrate suitability of design, then the licensee's design engineering organization and/or subject matter expert (program owners) involvement should be considered as early in the process as possible. Often, inclusion of these requirements in the purchase order renders the replacement item facility unique and requires that a specification be prepared to control qualification testing and resultant engineering approvals of the product reports.

Reverse-engineering efforts for items that have been environmentally and/or seismically qualified presents added risks. Design characteristics that support the item's qualification must be recognized and addressed.

Seismic qualification is generally dependent upon an item's material of construction, cross-sectional properties, natural frequency, mass, center of gravity, structural design, operating loads, and mounting. If any of these attributes are altered, an engineering analysis or complete requalification effort may be needed to justify the differences. If the user can demonstrate that the reverse-engineered item is equal to or better than the original item, either through similarity analysis or other technical justification, seismic requalification may not be required.

Reverse engineering of environmentally qualified items can be somewhat more complex. In addition to seismic concerns, the user must consider the effects of temperature, pressure, humidity, radiation, and spray upon an item. If a complete component is being reverse engineered, it is highly recommended to perform a new environmental qualification on the item due to the complex nature and potential synergistic effects of the environment on an item.

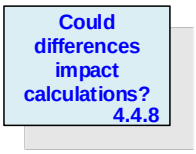
Frequently, it is more cost effective and timely to perform requalification at the component level than to analyze all the changes from the original item to the reverse-engineered item. However, if an item or subcomponent of a larger assembly is being reverse engineered, it may be viable to perform an analysis of the item. For example, if an O-ring for a pressure transmitter is being reverse engineered, then it is relatively simple to measure the original item's dimensions and compare them to standard manufacturing specifications for O-rings. The material can then be analyzed using FTIR or other accepted methods to determine the chemical composition of the material.

After these design characteristics are determined, then an acceptable reverse-engineered item can be manufactured or selected based upon those attributes without affecting the environmental qualification of the item or performing a new qualification effort. This process would have to be documented with an engineering analysis to accept the reverse-engineered item.

When environmentally or seismically qualified items are being reverse engineered, the key is to consider the item's attributes that directly support and/or could be affected by reverse engineering and provide documented justification for any changes that could affect those attributes.

If a review of (or new) equipment qualification activities is required, proceed to Step 4.7, Design engineering review. If a review of (or new) equipment qualification activities is not required, proceed to Step 4.4.8.

Step 4.4.8: Could differences impact calculations?



Description

Determine if differences between the original item and the reverse-engineered replacement could impact design calculations.

Methodology

If there are design characteristic changes introduced by the reverse-engineered items that impact design basis calculations that justify the suitability of the design, then the design engineering organization or the organization responsible for maintaining the calculation should be consulted

prior to acceptance of the replacement item. In many cases, a calculation update of this nature is an Operations-critical update which requires a design change or other design engineering input to support implementation.

If differences between the original item and the reverse-engineered replacement could impact design calculations, Step 4.7, Design Engineering review. If differences between the original item and the reverse-engineered replacement will not impact design calculations, proceed to Step 4.6, Item equivalency evaluation.

5
SPECIAL CONSIDERATIONS ASSOCIATED WITH THE USE OF REVERSE-ENGINEERING TECHNIQUES

5.1 Below the Level of Detail

During design and construction of nuclear power plants, design organizations typically develop *equipment-level* specifications to inform the procurement process. These specifications contain design requirements applicable to a particular component. These requirements include considerations such as operating conditions and extremes, product features, compatibility with process fluid, and the ability to withstand design basis events such as seismic events and loss-of-coolant accidents. Equipment specifications are sent to potential suppliers, who respond with proposals to use their products. Supplier proposals typically include specifications that describe the candidate equipment's capabilities, design features, and other information necessary for the licensee's design organization to incorporate the equipment in plant design (outline dimensions, interfaces, fits, etc.). The licensee's design organization evaluates the candidate proposals and selects the equipment best suited for use in the intended applications. Once selected, the licensee's design organization is responsible for establishing adequacy of design of the equipment. As required by 10CFR50, Appendix B, Criterion III [4], adequacy of design is typically established by methods such as design reviews, use of alternate or simplified calculation methods, or testing.

When the equipment selected by the licensee's design organization is procured, suppliers provide component-level information such as outline drawings, installation and maintenance manuals, and perhaps bills of material. However, the detailed design information considered during the equipment design process and information related to manufacture of the equipment, including part and material information, is considered proprietary by equipment manufacturers and is, therefore, not provided to the nuclear facility. This detailed information that is related to the product but not made available to the licensee is referred to as *below level of design detail* information.

Although reverse-engineering techniques are useful in recovering design information from an original item, certain design considerations and decisions made by the original manufacturer that were below the level of design detail provided to the licensee cannot always be recovered. Therefore, it is important to:

- Consider what these considerations may have been.
- Be cognizant of the design functions and interfaces of the item to which reverse-engineering techniques are being applied.

- Engage individuals with experience in designing and manufacturing the type of item to which reverse-engineering techniques are being applied (when appropriate).
- Collect and review all information available for the item to which reverse-engineering techniques are being applied.

5.2 Sources of Original Design Information

When applying reverse-engineering techniques, Figure 5-1 can be used as an aid in determining available sources of original design information. It can also be used to help identify the types of information that are unavailable so that consideration may be given to the impact that type of information might have on the function of the item to which reverse-engineering techniques are being applied. For example, if original manufacturing information is not available for a machined part, it may be necessary to pay particular attention to surface finish, since surface finish is often related to the manufacturing process and is often important to the function of the part.

Figure 5-1 provides a snapshot of the types of information typically available to the different entities involved in the design of plant structures, systems, components (SSCs), and parts. Although licensees and architect engineering (A/E) firms involved in plant design may have basic component-level information, only OEMs and their sub-tier suppliers have access to detailed part-level information typically included in purchase orders (POs), bills of material (BOMs) specifications, and manufacturing information.

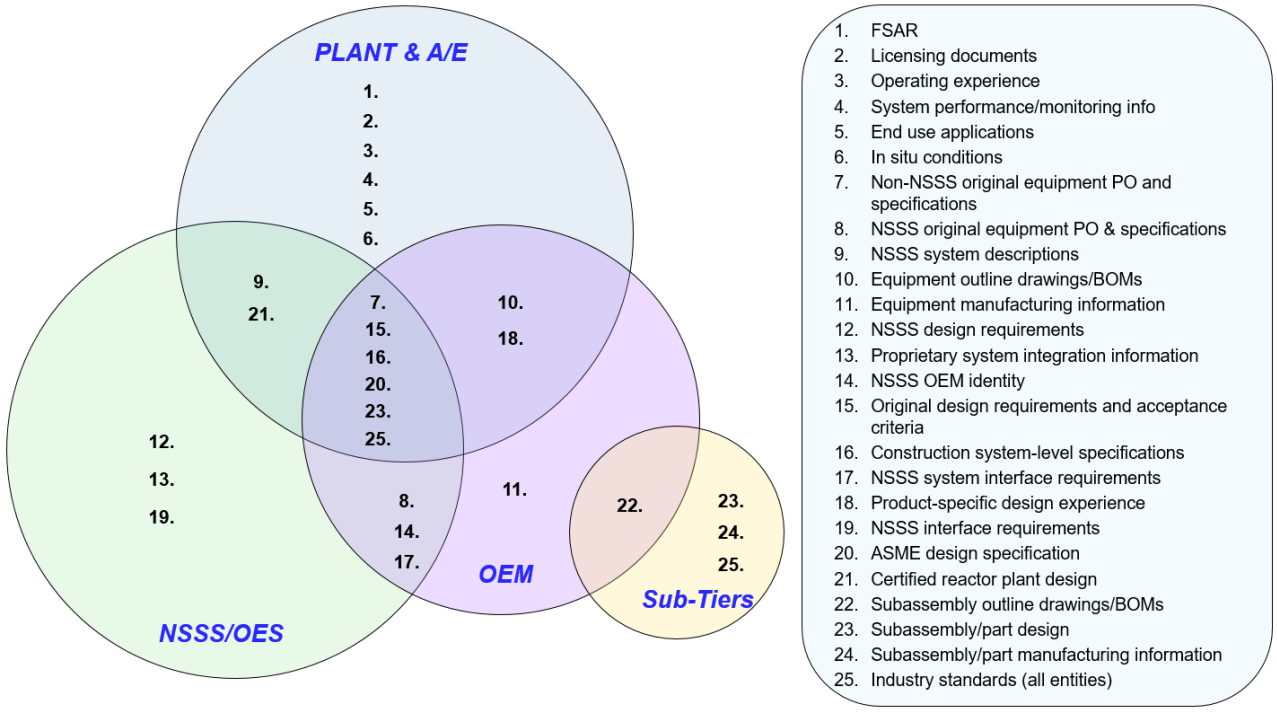


Figure 5-1
Design Information Typically Available to Plant, Design, and Supplier Organizations

6
INSPECTION, MEASUREMENT, AND TESTING OF MECHANICAL DEVICES

6.1 Special Considerations for Application of Reverse-Engineering Techniques to Mechanical Items

6.1.1 Configuration Using Inspection

In some cases, it may be difficult to define the configuration of items with complex geometry using basic inspection techniques. This is sometimes the case with castings, hand-crafted items, and other items where variation is inherent in the manufacturing process.

Advanced technologies such as laser and structured-light scanning discussed in Section 9 of this report facilitate extremely accurate recovery of configurational and dimensional information for mechanical items.

6.1.2 Material Identification

Metal materials are typically identified by a designation associated with a standard such as the unified numbering system (UNS) or American National Standards Institute (ANSI) designation and, in some cases, an associated standard such as ASME, ASTM, etc. Table 6-1 includes some of the test methods that can be used to identify material and indicates which are considered to be destructive. Table K-1 in EPRI 3002002982 [12] includes additional information on typical tests and examinations associated with material identification.

6.1.3 Material Condition Determination

The mechanical item material condition is a subset of material identifier (H1075, Condition A, etc.) usually having various degrees of mechanical properties. In some cases, this will be listed in the item description or markings on the items. When this is not the case, other means of identifying the condition should be used such as tensile testing, hardness testing, and so forth. Table 6-2 includes some of the test methods that can be used to identify material condition and indicates which are considered to be destructive. Table K-1 in EPRI 3002002982 [12] includes additional information on typical tests and examinations associated with material determination. The types of testing to which a specimen will be subjected should be agreed upon prior to testing and communicated to the licensee when or before the specimen is returned.

Table 6-1
Tests Useful in Material Identification

Ferrous and Nonferrous Metal Test	Considered Destructive?
Spark test	Yes
Chemical spot test	Yes
Positive material verification: x-ray fluorescence	No
Optical emission spectrographic analysis	Yes
Scanning electron microscope	No
Chemical analysis: wet chemistry or wet instrumental analysis, including inductive coupled plasma, mass spectrometer.	Yes
Infrared spectrometer (FTIR)	Yes
Wet chemistry: selective ion electrode, ion chromatography	Yes

Table 6-2
Tests Useful in Determining Material condition

Ferrous and Nonferrous Metal Test	Considered Destructive?
Bend	Yes
Corrosion	Yes
Elongation and reduction in area	Yes
Fatigue	Yes
Fracture toughness	Yes
Hardness/micro-hardness	Sometimes
Hardness/durometer	Yes
Impact	Yes
Optical emission spectroscopy	Yes
Tensile	Yes
Yield	Yes
Compression strength	Yes
Flexural strength	Yes
Shear	Yes

6.1.4 Coatings/Hard-Facing Identification Using Inspection

Items that have a direct interface with other metal items have a potential of having a much harder, wear-resistant surface coat applied to the substrate material. This material is used to provide a wear-resistant surface providing an extended life for the item as opposed to those items not including this feature. Typically, a weld overlay (hard facing) is applied via a weld, plasma spray, or other process involving materials such as cobalt-based materials. Cobalt has high strength and wear properties and can be applied using various methods to achieve the desired thickness.

Weld overlay (hard facing) may not be evident upon visual examination alone. Nondestructive chemical analysis should be performed prior to any destructive testing to determine if there are dissimilar materials present on the specimen. Destructive testing is typically required to determine the materials, chemistry, and strength of the overlay as well as the configuration of the base metal condition prior to the overlay being applied when dissimilar materials are present in the specimen. This ensures that the proper configuration and thickness are determined and specified.

Many types of coatings exist, and some are proprietary. It may be difficult to uncover the properties of proprietary coatings using nondestructive inspection techniques. Engineering analysis of the item's function and interfaces should be used in cases where it is not possible to identify configuration, material, material condition, coatings, or hard facing using available inspection methods.

6.2 Practical Considerations for Mechanical Items

The following guidance should be considered when implementing reverse-engineering techniques for mechanical items.

- Bearings – Document the bearing housings and shaft fits for rotating components during the disassembly process. Where fits are not within standards specified by the ABMA, do not automatically assume a manufacturing error. Non-standard bearing-to-shaft fits may be used in some equipment.
- Thread form – Avoid assumptions concerning the use of standard screw threads. Often, manufacturers use unique screw threads to prevent others from copying them or substituting standard-threaded parts. Measure and compare pitch diameter to industry standards such as Federal Standard-H28A [13].
- Clearances – Note all clearances measured during the disassembly process to assist in establishing tolerances for individual parts. This includes:
  - Lateral movement
  - Backlash (gears, splines, etc.)
  - Torque
  - Keyway clearances
  - Cross-section welded joints to determine the depth of penetration, penetration treatment, and the length and size of fillets and bevels

- Features without apparent purpose – Note features on parts that appear to have no useful function for the item's intended use. Features such as holes or protrusions may have been designed to facilitate the manufacturing process. Indicate those features as optional on final drawings for the manufacturer of the reverse-engineered item.
- Punched items – Be aware that, normally, items that are sheared or punched do not require a good surface finish of the sheared edge. However, in some cases, the manufacturer intentionally punches a hole with a minimum of clearance between the punch and die to create a larger "straight land" in the hole. This may be required as a load bearing surface or to minimize wear on mating parts.
- Cast or molded parts – In addition to the draft and parting lines on injection molded or investment cast parts, note ejection pin locations for inclusion on the final drawing as an allowable feature.
- Joining methods – Understand that joining methods such as riveting or spot welding may require pull tests to determine strength requirements.
- Heat treatment – Evaluate heat treatment, using cross sections as required to determine case depth, grain structure, and other metallurgical requirements. Note the grain flow on forgings.
- Bushing fit – Measure the concentricity of pressed-in bushings relative to the diameter, securing them during the disassembly process.
- Dowel pins – If dowel pins are used to align mating parts, ensure the proper location of the pins at the projected distance to ensure proper fits of those parts.
- Finish of mating surfaces – Check the surface finishes on all mating surfaces, regardless of whether a gasket is used.
- Casting surfaces – Examine casting surfaces that are subject to wear for grain structure variances caused by special casting processes such as "chills" to harden the casting during the manufacturing process.

7
INSPECTION, MEASUREMENT, AND TESTING OF ELECTRICAL AND ELECTRONIC DEVICES

7.1 Special Considerations for Application of Reverse-Engineering Techniques to Electrical and Electronic Items

Reverse engineering of electrical/electronic components and items presents unique situations that require special consideration. The primary need for reverse engineering is due to obsolescence and the recurring introduction of new technologies.

Most electrical and electronic reverse-engineering projects result in design upgrades because the discrete electronic components available for use in the replacement employ current technologies. Electronic piece-part component replacements also likely require substitution.

7.2 Specialized Electrical/Electronic Reverse-Engineering Tools

There are many advanced technologies today that allow the engineer to simulate circuit designs on a computer without the need to “breadboard” the design. This allows the engineer to optimize the reverse-engineered design even before manufacturing a prototype, and it substantially reduces the associated risk.

Circuit modeling software has become a common tool in both classical circuit design and reverse-engineering applications. The simulation scenarios are almost endless for both analog and digital circuitry. Some circuit simulation analyses include bias point analysis, direct current (DC) sweep analysis, transient analysis, alternating current (AC) sweep analysis, parametric analysis, noise analysis, temperature analysis, Monte Carlo analysis, and digital timing analysis.

Individual circuit components can be selected from component databases containing upwards of 20,000 records. If a particular component is not contained in the database, it can be created and added to the specific component library.

After the prototype is approved, advanced manufacturing methods can be used to ensure that the manufactured item conforms to the design schematic. Specialized equipment can automatically test circuits at preprogrammed points to verify the proper signal path, continuity, and other functional requirements.

7.3 Electrical/Electronic Analysis

Electrical/electronic analysis defines the inputs, outputs, component characteristics, circuit paths, materials, bonding, circuit board technology, and soldering methods to reproduce the item through reverse engineering. Available documentation must be validated through inspection, functional testing, and measurement.

If little or no documentation is available, the information must be recovered through other means such as:

- Input/output parameters should be determined from the next higher- and lower-level assembly, as appropriate.
- Circuit paths should be traced and verified.
- Individual circuit components should be inspected and identified, and functional characteristics determined.
- Component substitution lists should be compiled.
- An "equivalent" circuit should be designed, tested, and verified to meet the original design functional requirements.

If substantial component substitutions were made, the functional characteristics of the circuit must be verified. Depending upon whether the reverse-engineered circuit is analog or digital, the following characteristics should be verified, as applicable:

Analog Circuits

- Stability
- Step response
- Frequency response
- Gain
- Phase linearity
- Slew rate
- Non-linear characteristics
- Thermal characteristics
- Ripple and noise
- Input/output signal response
- Input/output impedance
- Power consumption (min/max)
- Special functional characteristics

Digital Circuits

- Input/output level
- Proper bias levels
- Rise/fall time of signal pulses
- Clock frequency and duty cycle
- Circuit interaction and component characteristics

- Thermal characteristics
- Functional parameters of circuits
- Fault tolerance
- Power consumption (min/max)
- Special functional characteristics

Any additional qualification criteria of the reverse-engineered circuit should be addressed including, as applicable, temperature, humidity, seismic levels, EMI/RFI immunity, radiation, pressure, degraded voltage, and other criteria, as appropriate. Depending upon the level of component substitution, previous environmental/seismic and EMI/RFI qualification reports of the original item may be invalidated, and a new qualification may need to be performed on the reverse-engineered item.

Component substitutions that involve replacement of analog devices (for example, transistors) with digital devices (for example, erasable programmable read-only memory [EPROM]) typically have the potential to introduce new failure modes and be subject to cyber security considerations. Additional information is available in EPRI 3002007023, *Digital Equivalency Evaluation Screening Checklist and Considerations* [14].

7.4 Practical Considerations for Electrical and Electronic Items

The following guidance should be considered when implementing reverse-engineering techniques for electrical items:

- Wire and cable – Measure electrical wire diameters, and note the insulation type, thickness, and manufacturer. Duplicate the length of wire even if it appears to be excessive. Shortening a length of wire could change the electrical characteristics of the end item.
- Thermal expansion – Be aware of the differential thermal expansion of dissimilar materials.
- Electronics – Be aware that electronic/electrical bills of materials should be prescriptive enough to positively identify discrete components by voltage rating, current rating, tolerance, temperature coefficient, specific component type (for example, tantalum capacitor, wire-wound resistor), etc.
- Hand-matched discrete components – Be aware that some electronic/electrical circuits contain matched components to achieve special circuit operating characteristics and will not function properly otherwise.

7.5 Examples of Electronic Reference Standards

The following four standards are examples of standards that might be considered when implementing reverse-engineering techniques for electronic and electromechanical devices. There are many other standards that address manufacturing and inspection of different product types. Standards appropriate for the product type should be considered.

IPC-A-600F, Acceptability of Printed Circuit Boards [15]

Contains visual illustrations of preferred, acceptable, and non-conforming conditions for plated through-holes, surface plating, solder coating, base materials, etching, conductors, mechanical processes, flexible and multilayer boards, bows/twists, flat cable, and other conditions of printed wiring boards.

IPC-A-601F, Acceptability of Printed Board Assemblies [16]

Provides workmanship criteria with photographs and schematic illustrations covering:

- Handling electronic assemblies
- Electrical overstress and electrostatic discharge damage prevention
- Mechanical assembly
- Component installation location/orientation soldering
- Cleanliness
- Markings
- Coatings
- Laminate conditions
- Surface mount assemblies
- Discrete wiring assemblies
- PTH/surface mount assemblies

J-STD-001F, Requirements for Soldered Electrical and Electronic Assemblies [17]

Industry standard for commercial and high-reliability assemblies. MIL-STD-2000A [18] has been canceled, leaving this standard as the sole industry consensus for soldering.

IPC-D-330, Design Guide Manual [19]

Industry-approved guidelines for layout, design, and packaging of electronic interconnections. Provides references to pertinent specifications—commercial, military, and federal.

8
ESTABLISHING TOLERANCES

8.1 General Guidance

Determining/establishing tolerances is not a random process. It requires engineering judgment based upon reverse-engineered data, design calculations, production facilities, and cost. Tolerances should be appropriate for the specific application because tolerances determine manufacturing methods, determine the selection of production facilities capable of obtaining tolerances, and directly affect production costs. The engineer must be aware of the effect of tolerances on production costs and facility capability. The chart in Figure 8-1 from *Machine Design, Theory, and Practice* [20] illustrates the relative cost of production as a function of tolerances.

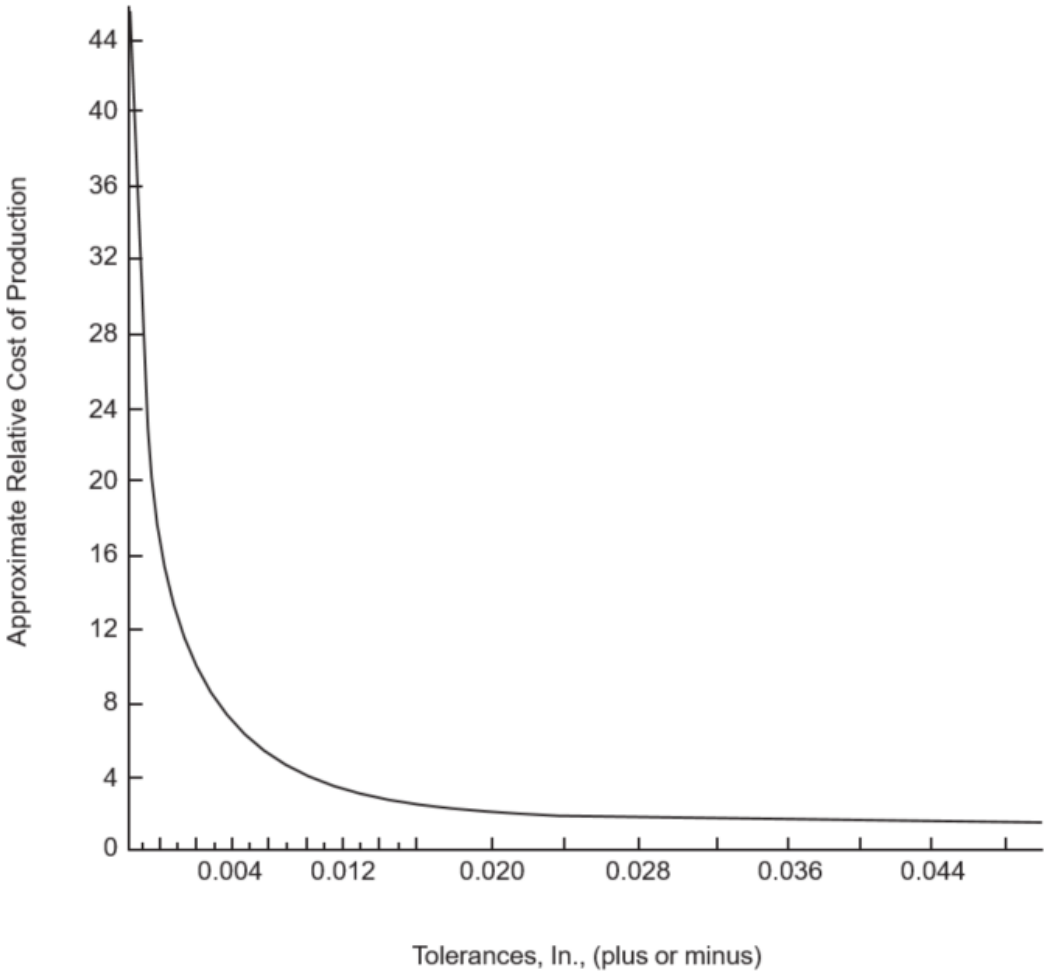


Figure 8-1
Relative Cost of Production Versus Tolerances [20]

8.2 Basis for Establishing Tolerances

The general basis for establishing tolerances between mating parts is the type of fit that the mating parts share. *Fit* is the general term used to define the range of tightness or looseness required of mating parts. There are three basic types of fits:

- Clearance fit: A fit where an air space or "clearance" always results between the internal member and the external member of an assembly. A clearance fit is always positive.
- Interference fit: A fit where the internal member is larger than the external member such that there is always an actual "interference" of metal. Interference fits are always negative.
- Transition fit: A fit where either a clearance or an interference fit can result when the external member and internal member are assembled.

The type of fit selected for a particular design is based upon the required function of the assembly as defined by the particular class of fit. Classes of fits can be categorized as a running or sliding fit, locational clearance fit, transition fit, locational interference fit, and force or shrink fit. Fits are governed by ANSI B4.1, "Preferred Limits and Fits for Cylindrical Parts" [21]. When tolerances of mating mechanical parts are being established, the type of fit and the application should always be considered.

Section 8.10 provides a listing of standards related to determining fits and tolerances that may be considered when implementing reverse-engineering techniques.

8.3 Item Interfaces

Access to mating or interfacing items and/or the assembly of which the item is a part is paramount in establishing an item's fits and tolerances. Analysis of mating items provides an indication of the type of fit used by the original design (for example, interference fit, clearance fit). Additionally, there are standards that specify fits for mating parts, such as standard bearing-to-shaft fits established by the ABMA. ANSI B4.1 [21] delineates standard limits and fits for cylindrical parts. Consideration should be given to materials of construction for mating parts to account for potential different temperature coefficients of expansion. Heat treatment conditions and surface finishes of mating parts can also provide an insight to the type of fit required.

8.4 Consult a Manufacturer

Another excellent source for identifying proper fits and tolerances is a manufacturer of the type of item being reverse engineered. This does not have to be the OEM or OES of the original item, but it should be a manufacturer of the same type of component. Sometimes fits and tolerances are established based upon standard industry practices that are common among manufacturers of the same type of component.

Manufacturers or designers of electronic components can be helpful in identifying situations that require matched electronic components.

8.5 Manufacturing Processes

Standard fits and tolerances can be based upon the type of manufacturing process used to fabricate the item. If the manufacturing method can be determined, the standard tolerance can be determined with reasonable assurance. Figure 8-2 and Table 8-1 illustrate typical manufacturing methods in relation to standard tolerance grades based upon part size.

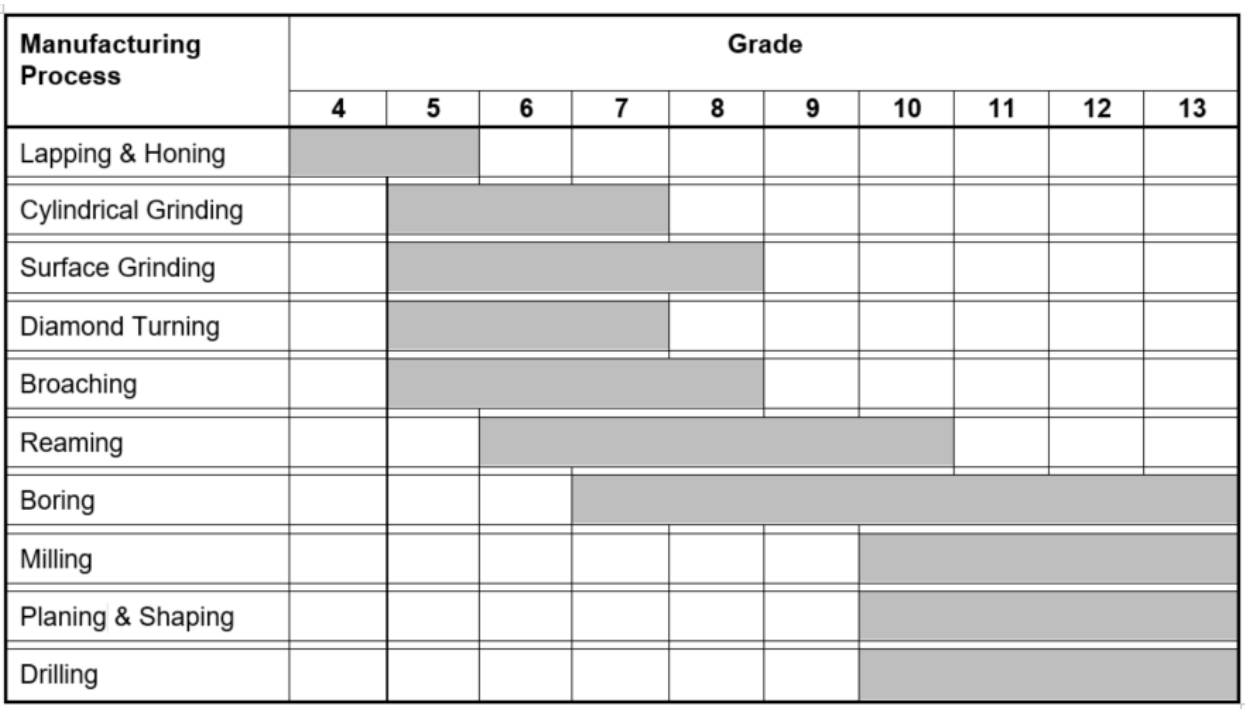


Figure 8-2
Relationship of Manufacturing Processes and Tolerances [22]

8.6 Surface Finish

Most manufactured parts do not require any special quality of surface finish other than that obtained by the method of fabrication. Figure 8-3 illustrates the relationship between surface finishes and some common components. However, components such as bearings, shafts, cylinders, and components requiring special fits (for example, interference, clearance, etc.) may require special post-fabrication surface finishes.

Figure 8-4 illustrates the relationship between surface finishes and manufacturing processes. Therefore, obtaining the quality of the surface finish through reverse-engineering methods is an indication of the part criticality and/or manufacturing methods, which can be directly related to tolerances. It should be noted that tighter tolerances require finer surface finishes; therefore, the design of the part should be commensurate with the manufacturing method needed to achieve the required surface finish without additional machining. It should be noted that the designer most likely selected the least costly manufacturing method to achieve the required finish on a given part in order to reduce production costs. Figure 8-5 illustrates the relative cost of achieving specific surface finishes.

Table 8-1
Standard Tolerances and Grades [21]

Nominal Size - Inches (0ver-to)	Grade									
	4	5	6	7	8	9	10	11	12	13
	Tolerance in thousandths of an inch									
0–0.12	0.12	0.15	0.25	0.4	0.6	1.0	1.6	2.5	4	6
0.12–0.24	0.15	0.20	0.3	0.5	0.7	1.2	1.8	3.0	5	7
0.24–0.40	0.15	0.25	0.4	0.6	0.9	1.4	2.2	3.5	6	9
0.40–0.71	0.2	0.3	0.4	0.7	1.0	1.6	2.8	4.0	7	10
0.71–1.19	0.25	0.4	0.5	0.8	1.2	2.0	3.5	5.0	8	12
1.19–1.97	0.3	0.4	0.6	1.0	1.6	2.5	4.0	6	10	16
1.97–3.15	0.3	0.5	0.7	1.2	1.8	3.0	4.5	7	12	18
3.15–4.73	0.4	0.6	0.9	1.4	2.2	3.5	5	9	14	22
4.73–7.09	0.5	0.7	1.0	1.6	2.5	4.0	6	10	16	25
7.09–9.85	0.6	0.8	1.2	1.8	2.8	4.5	7	12	18	28
9.85–12.41	0.6	0.9	1.2	2.0	3.0	5.0	8	12	20	30
12.41–15.75	0.7	1.0	1.4	2.2	3.5	6	9	14	22	35
15.75–19.69	0.8	1.0	1.6	2.5	4	6	10	16	25	40
19.69–30.09	0.9	1.2	2.0	3	5	8	12	20	30	50
30.09–41.49	1.0	1.6	2.5	4	6	10	16	25	40	60
41.49–56.19	1.2	2.0	3	5	8	12	20	30	50	80
56.19–76.39	1.6	2.5	4	6	10	16	25	40	60	100
76.39–100.9	2.0	3	5	8	12	20	30	50	80	125
100.9–131.9	2.5	4	6	10	16	25	40	60	100	160
131.9–171.9	3	5	8	12	20	30	50	80	125	200
171.9–200	4	6	10	16	25	40	60	100	160	250

Surface or Part	Maximum Roughness (micro-inches, rms)																					
	1	2	3	4	5	6	8	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250
Valve Stem (Automotive)										■												
Cylinder Bores										■												
Seals (Anti-Friction Bearing Races)					■																	
Worm Gears - General													■									
Worm Gears - Heavy Loads										■												
Rolling Surfaces - General (Cams)																■						
Rolling Surfaces - Precision (Heavy)							■															
Rotating Surfaces - General													■									
Rotating Surfaces - Precision										■												
Surfaces for Copper Gaskets													■									
Surfaces for Soft Gaskets																			■			
Surfaces of Fluid Seals					■																	
Ground Screw Threads & Worms										■												
Pressure Lubricated Bearings					■																	
Piston Rods										■												
Housing Fits (No Gasket or Seal)																			■			
Slide Ways & Gibs													■									
Teeth of Ratchets & Pawls																■						
Valve Seats							■															
Gear Teeth (Heavy Loads)										■												
Gear Teeth (Over 10 DP)																■						
Gear Teeth (Under 10 DP)													■									
Journal Bearings (General)													■									
Journal Bearings (Precision)										■												
Rolled Threads							■															
Die or Top Cut Threads																			■			
Clearance Surfaces (Machined))																						■
Datum Surfaces (Tol <0.001 in)																■						
Datum Surfaces (Tol >0.001 in)																			■			
Push Fits													■									
Milled Threads																■						
Sliding Surfaces of Mating Parts													■									
Pressed Fits - General																■						
Valve Seats							■															
Mating Surfaces (Faces, Pads, etc.)																			■			

Figure 8-3
Representative Surface Finish of Common Components [23]

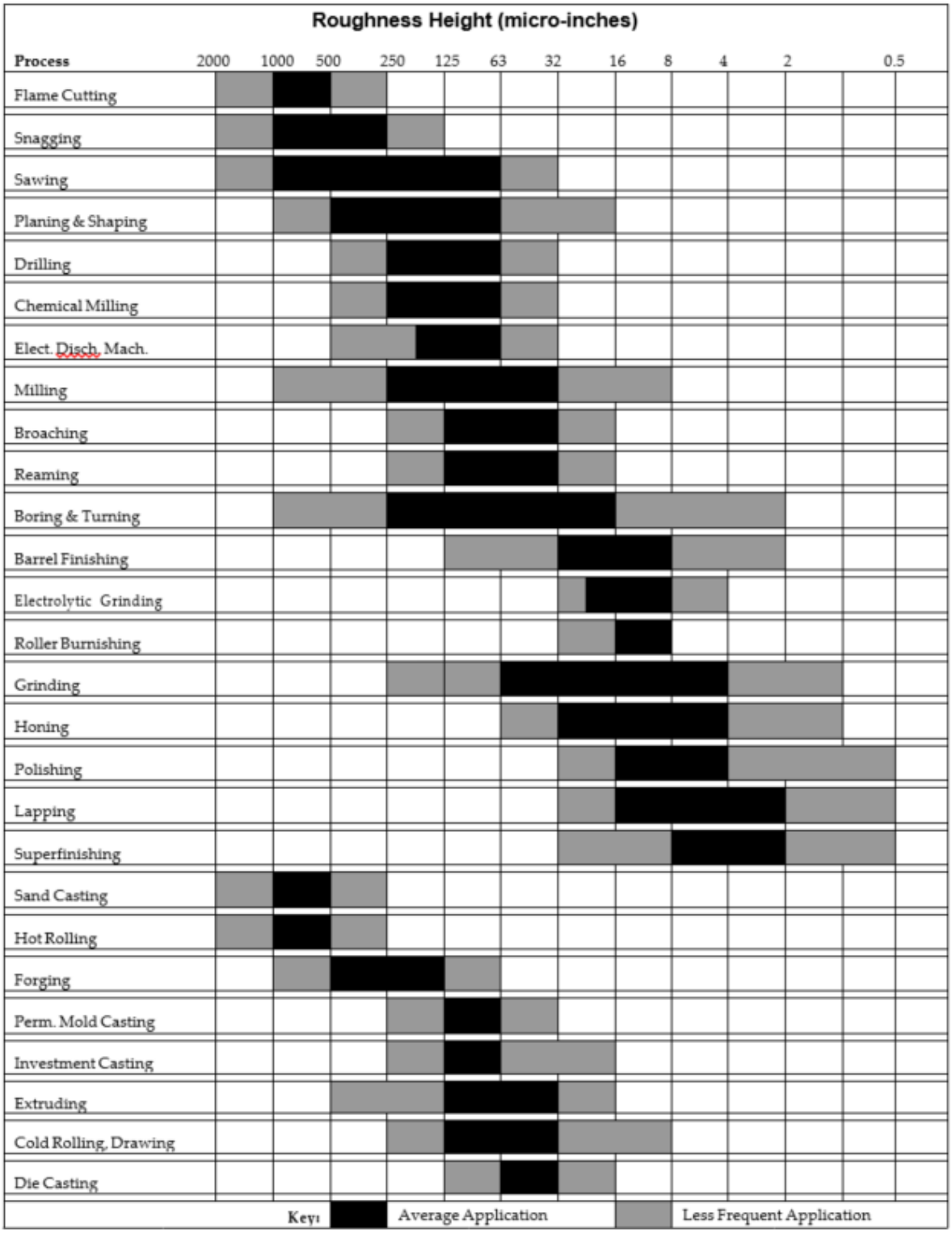


Figure 8-4
Relationship of Surface Finish to Manufacturing Processes (ANSI B46.1) [24]

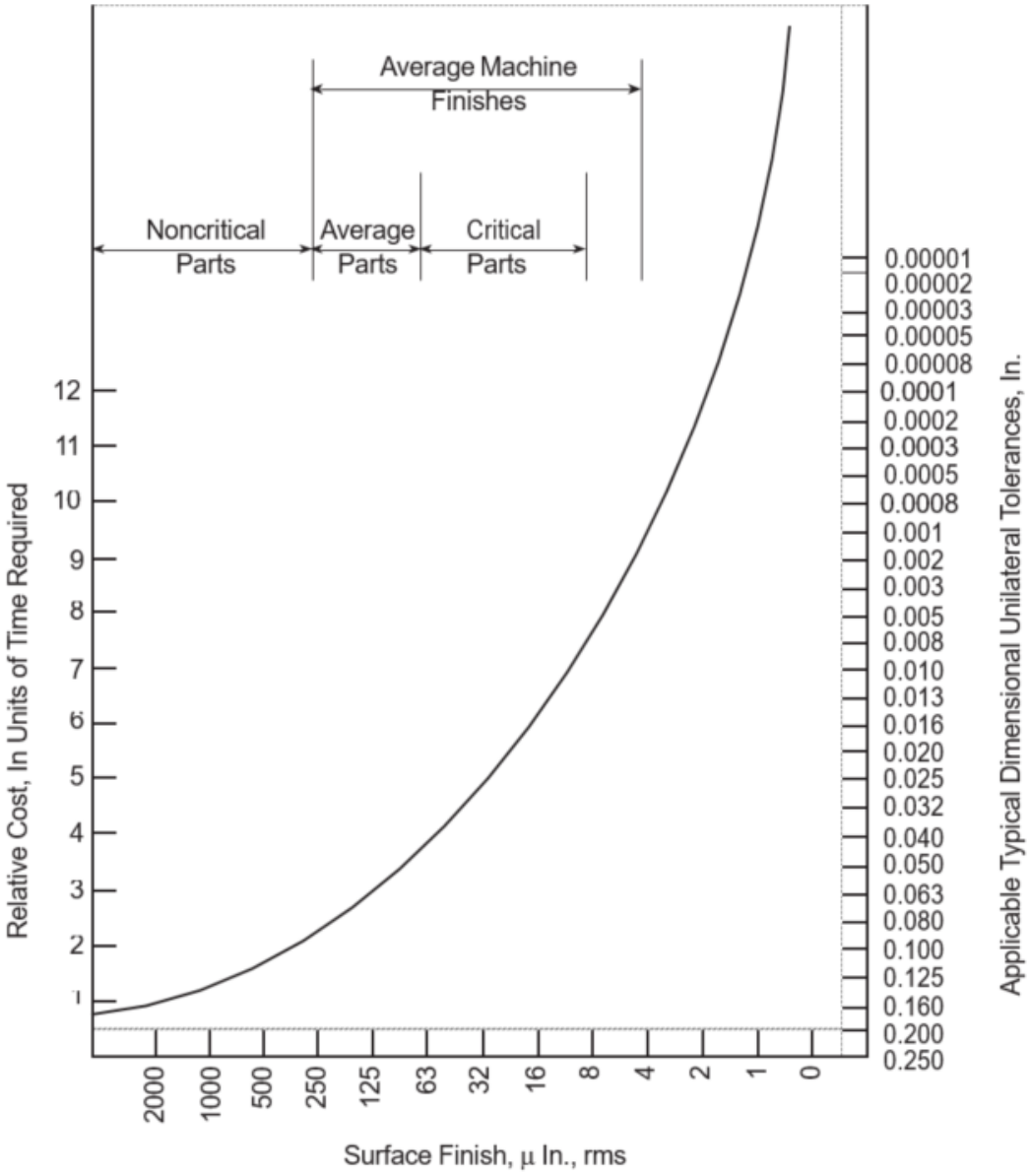


Figure 8-5
Relative Cost Versus Surface Finish [20]

8.7 Scientific Methods of Establishing Tolerances

Establishment of tolerances today is generally performed in an iterative process. The design engineer establishes a theoretical value based upon design parameters. This is then reviewed by the manufacturing engineer and production personnel who refine the tolerance based upon production costs, production methods, and manufacturing capability. To supplement methodology typically used, scientific methods being researched to establish tolerances are broken down into two groups: (1) tolerance analysis and (2) tolerance allocation. Tolerance analysis is used when component tolerances are known, and the resultant assembly tolerance is calculated. Tolerance allocation is used when the assembly tolerance is known, and the component tolerances are allocated.

8.7.1 Tolerance Analysis

The purpose of calculating an assembly tolerance is to specify actual assembly tolerances so that sound predictions can be made on the number of rejects or scrap. There are eight basic tolerance analysis models that are based upon mathematical models as follows:

(1) Worst-case model

The worst-case model can be expressed as follows:

$$t_a = \sum_{i=1}^{n} t_i$$

Where:

t_i is the specified tolerance for component i

i = 1, ... ,n

t_a = assembly tolerance

This method produces the most conservative assembly tolerance value. The calculated assembly tolerance tends to be much higher than the practical assembly tolerance, thereby forcing individual allocated component tolerances to be very tight in order to meet the overall assembly tolerance. This results in high manufacturing costs. However, this method can be used when the production lot is small, all assemblies must be within allowable limits, and no rejects are permitted.

(2) Statistical model

The statistical model can be expressed as follows:

$$t_a = z_a \left(\sum_{i=1}^{n} \left(\frac{t_i}{z_i} \right)^2 \right)^{0.5}$$

Where:

t_i is the specified tolerance for component i

i = 1,....,n

t_a = assembly tolerance

Z_a = assembly deviation multiplier

Z_i = deviation multiplier for the i^{th} component tolerance

For normal distributions, the deviation multiplier is normally set to 6 when 6-sigma limits are considered. This model produces smaller assembly tolerances, especially when the number of subcomponents is large or when individual component tolerance distributions are symmetrical around the tolerance midpoint.

(3) Spott's modified model

This model can be expressed as follows:

$$t_a = 0.5\left(\sum_{i=1}^{n} t_i + \sum_{i=1}^{n}\left(\frac{t_i}{z_i}\right)^2\right)^{0.5}$$

This model is a combination of the worst-case model and the statistical model with Z_a and Z_i set to 6 for all i. This model is used when the subcomponent distributions are skewed.

(4) Modified statistical model

This model can be expressed as follows:

$$t_a = c_f z_a\left(\sum_{i=1}^{n}\left(\frac{t_i}{z_i}\right)^2\right)^{0.5}$$

This model takes into account nonrandom factors such as errors in predicting component tolerance distributions. A correction factor, c_f, is introduced to account for process errors. Several correction factors as a function of the number of subcomponents and the number of rejects have been suggested. For most applications, a correction factor of 1.4 or 1.5 is considered acceptable. This method is not suitable when the number of subcomponents is large or the subcomponent tolerance distributions are not symmetrical.

(5) Moment model

In this model, the subcomponent maximum dimension (X_{max}) and the minimum dimension (X_{min}) are calculated using the mean and standard deviation of component tolerance values as follows:

$$x_{\max} = m_a + 3\sigma \text{ and } x_{\min} = m_a - 3\sigma$$

Where:

$$m_a = \sum_{i=1}^{n} m_i$$

$$\sigma_a = \left(\sum_{i=1}^{n} \sigma_i^2\right)^{0.5}$$

$t_a = x_{max} - x_{min}$

m_a = assembly mean tolerance

m_i = component mean tolerance

δ_a = standard deviation of the assembly tolerance

δ_i = standard deviation of the i^{th} subcomponent tolerance

Other models used under tolerance analysis are the m model, the Monte Carlo model, and the hybrid model, which are variations of the above models.

The above models can be used to complement the experience method or augment design engineering analysis of tolerance specification. Various software packages are available on the market that employ some of the basic mathematical models presented here.

8.7.2 Tolerance Allocation

Tolerance allocation is the process of allocating subcomponent tolerances while observing the total assembly tolerance. This methodology is centrally focused on the reduction of production costs for medium-to-large-scale manufacturing operations.

For purposes of reverse-engineering in the nuclear industry, reducing production costs is not the central issue; therefore, the present methodologies of tolerance allocation do not meet the needs of the industry and are not presented in this guideline in detail.

8.8 Tolerance Stack-Up

During classical design activities, it is relatively simple to calculate tolerance stack-up to avoid an undesirable fit condition. For example, in an application that requires a clearance fit, the designer ensures that the mating components do not result in an interference fit by calculating the maximum allowed tolerances from component to component and verifying that the result maintains a positive allowance between mating parts. However, in the reverse-engineering process, normally there are not sufficient data related to mating parts to perform a tolerance analysis.

To reduce the potential detrimental effects of tolerance stack-up, the engineer must be aware of the relationship of the item to its mating parts and/or the next higher-level of assembly and avoid determining tolerances of the item in a “vacuum.” Analyzing and inspecting multiple items and their associated mating parts and higher-level assemblies also provide additional information on tolerance stack-up.

The engineer should be cognizant of the required relationship of the mating parts. Does the configuration for a particular application require an interference fit or a clearance fit? The engineer should consult with machinists, manufacturing engineers, and other subject matter experts knowledgeable about the equipment and application being analyzed. Overall, the engineer must use sound engineering judgment to avoid undesirable tolerance stack-up.

8.9 Special Considerations for Electrical/Electronic Tolerances

When reverse engineering and/or substituting components on electrical/electronic items, consideration should be given to the possibility that electronic piece-parts may be a matched set or hand selected for special characteristics. This can occur in applications when a certain subcomponent characteristic is critical to the overall operation and function of the circuit.

Tolerances of these items are more critical than simply selecting replacement components based upon existing component markings. Tolerance of the component in relation to its matched component also becomes critical and should be considered. If the components are not matched

properly, frequently the unit may not function within specified characteristics or may not function at all. Original circuit schematics, knowledgeable electronic designers, and/or knowledgeable technicians are helpful when identifying requirements for matched or hand-selected components.

8.10 Standards and Other References for Establishing Tolerances

Table 8-2 provides a listing of common standards and references that may be considered when establishing tolerances.

Table 8-2
References for Establishing Tolerances

Designation	Title
ABMA-STD-4 [25]	Tolerance Definitions and Gauging Practices for Ball and Roller Bearings
ANSI B4.1 [21]	Preferred Limits and Fits for Cylindrical Parts
ANSI B4.2 [26]	Preferred Metric Limits and Fits
ANSI B46.1 [24]	Surface Texture
ANSI Y14.5M [27]	Dimensioning and Tolerancing
ANSI B89.3.1 [28]	Measurement of Out-of-Roundness
BS-6954-2 [29]	Recommendations for Statistical Basis for Predicting Fit Between Components Having a Normal Distribution
ISO-286-1: Part 1 [30]	Bases of Tolerance, Deviations and Fits, ISO System of Limits and Fits
ISO-286-2 - Part 2 [31]	Tables of Standard Tolerance Grades and Limit Deviations for Holes and Shafts
ISO-R468 [32]	Surface Roughness
ISO-R1938 [33]	Systems of Limits and Fits for Metric Units
ISO-3443-2 -Part 2 [34]	Statistical Basis for Predicting Fit Between Components Having a Normal Distribution
MIL-I-25260 [35]	Assembling and Staking of Interference-Fit Part
	Machine Design, Theory and Practice, Aaron D. Deutschman et al. Macmillan Publishing, New York, NY [18]
	Machinery’s Handbook, Erik Oberg et al. Industrial Press, New York, NY [22]

9
ADVANCED REVERSE-ENGINEERING TECHNOLOGIES

As advances in manufacturing are made, an increasing number of technologies are developed that find application in supporting reverse-engineering activities. The following are examples of complex technologically advanced systems that are available for use when applying reverse-engineering techniques:

- Laser and structured-light computer scanning
- X-ray computed tomography (CT) scanning
- X-ray fluorescence spectrometer
- Electronic contact computer scanning
- Additive manufacturing (three-dimensional [3D] printing)
- Printed circuit board scanning

These systems are complex in nature and often require special installation, environmental controls, and operation by qualified personnel. They are based upon the same basic methodology:

1. Scan the original specimen.
2. Digitize the data acquired from the scan.
3. Convert the data into a usable format for use in computer-aided design (CAD)/computer-aided manufacturing (CAM) systems.
4. Assign tolerances.
5. Manufacture a prototype or final-use item.

9.1 Laser and Structured-Light Scanning

Laser computer scanning is a technology that operates by emitting a low-energy laser beam on the specimen to be scanned. The laser is rotated 360° around the specimen to obtain optimum data points. The captured variations of the reflected laser light are digitized and converted to 3D images by the computer. Structured-light 3D scanners project a pattern of light on the object using either a liquid crystal display (LCD) projector or other stable light source. Cameras, offset slightly from the pattern projector, use the shape of the light pattern to determine the location of points in the field of view. The advantage of structured-light 3D scanners is speed and precision. Instead of scanning one point at a time, structured-light scanners can scan multiple points at once. Typical 3D scanners can consistently measure with an accuracy of 10 microns and repeatability of 5 microns. Disadvantages of some of these scanners include difficulty in accurately measuring items with changing surface reflectivity, optics performance, and detector

limitations. Most scanners require a special vibration-resistant foundation, special lighting, and an environmentally controlled atmosphere. The systems are relatively simple to operate and could easily be operated by personnel familiar with CAD/CAM-type equipment. Table 9-1 identifies typical use and limitations of scanning technologies.

Table 9-1
Examples of Items that Can Be Scanned Using Advanced Technologies

Technology	Typical Uses	Notes/Limitations
Hand-held 3D scanner	Couplings, rings, brackets, flanges, hardware, items in the field that cannot be easily shipped	Shiny objects may need special preparation or use of targets.
Articulated arm 3D laser scanner	Couplings, rings, brackets, flanges, hardware, impellers, columns	Not as mobile as handheld versions.
Structured-light 3D scanner	Non-shiny objects, couplings, rings, brackets, flanges, hardware, impellers, columns	Shiny objects may need special preparation or use of targets.

Use of the FARO Edge with the Laser Line Probe high-definition scanner shown in Figure 9-1 and Figure 9-2 is being researched by Duke Energy's Procurement Engineering group.



Figure 9-1
Preparing to Scan a Part Using a FARO Three-Dimensional Scanner at Duke Energy's Central Receiving and Dedication Facility

The FARO arm shown in Figure 9-1 is a seven-axis, articulated arm that works in conjunction with a high-definition scanner attached to the arm. Each joint on the arm has a rotary optical encoder. The signals from these encoders are processed and sent to a computer. The instrument is accurate to ± 0.001 inch. Software is used to capture the data (point cloud) and allows technicians to create editable solid models such as those shown in Figure 9-3 and Figure 9-4 with

compatible CAD software. Point cloud processing can be used as a foundation to create a solid model where design and manufacturing drawings can be produced. The software can be used to compare scan to scan or scan to CAD to quickly analyze dimensional deltas between the items so that variations can easily be identified prior to installation in the field.



Figure 9-2
Dynamic Scanning of a Specimen Item Using FARO Edge with Laser Line Probe HD to Capture the Data Set for the Development of a Point Cloud

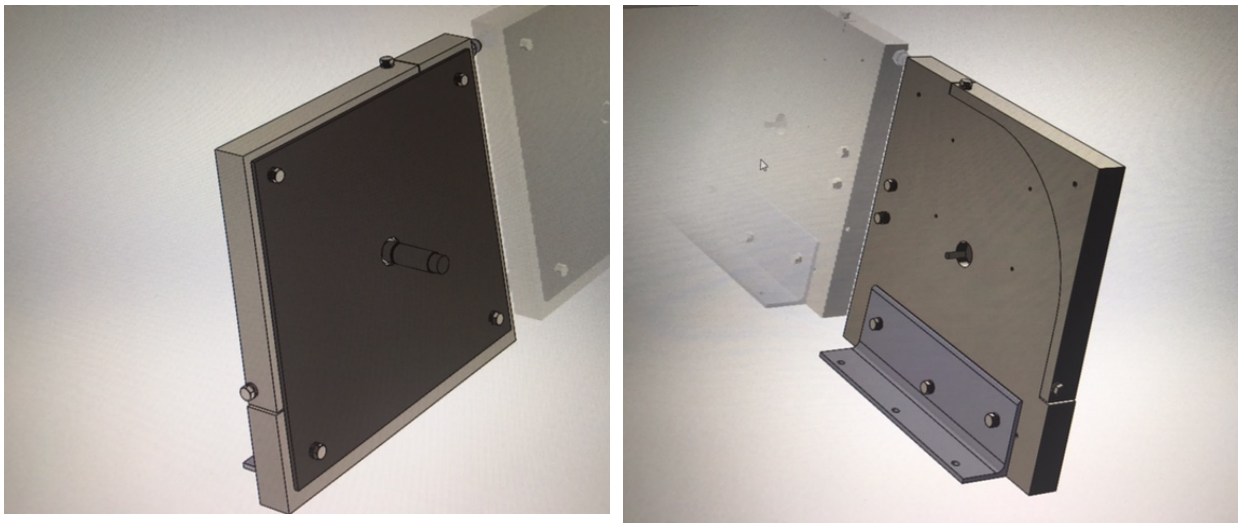


Figure 9-3
After 3D Scanning Individual Piece Parts into Geomagic Design X, Individual 3D Models Were Developed Using SOLIDWORKS and Assembled to Test the Fit-Up.

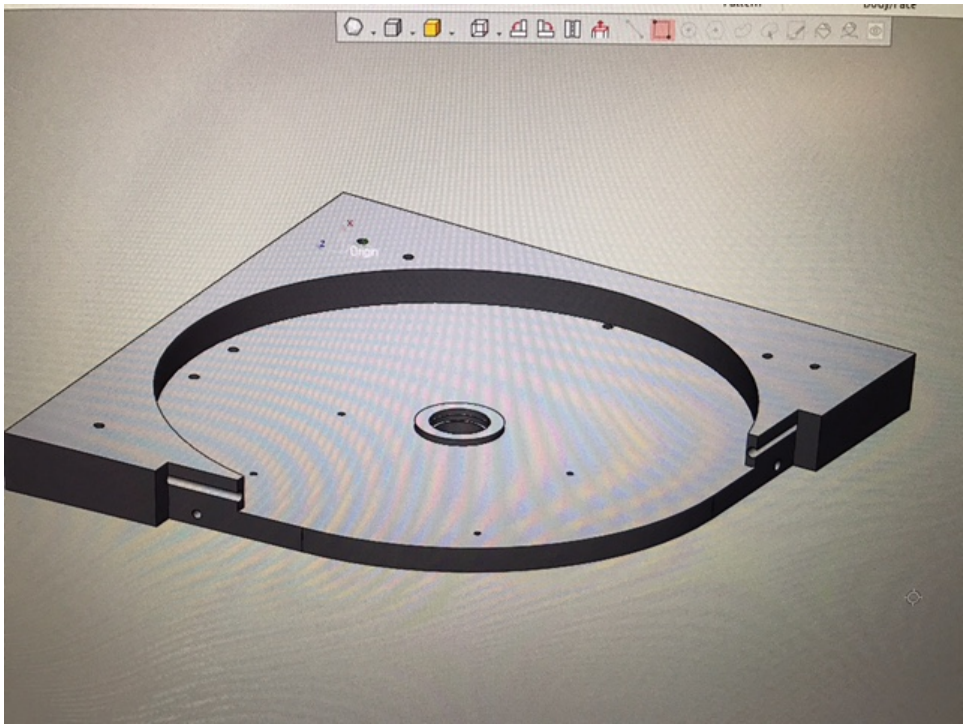


Figure 9-4
A 3D Model Developed in SOLIDWORKS from a Point Cloud Processed in Geomagic Design X. The 3D Models Will Be Used to Create Two-Dimensional (2D) Drawings for Fabrication Purposes.

9.2 X-Ray CT Scanning

X-ray CT is a system that measures and assesses an item's dimensional attributes by emitting a flux of photons onto the specimen through a radiation source such as an x-ray tube, x-ray linear accelerator, or gamma-ray emitting radioisotope. High-energy photons pass through the specimen onto a detector array. The detector converts the light into visible, digitized, analog light events, and then the computer converts the data, calculating density matrices and the specimen's image, including dimensional information. Rotating the specimen in the radiation beam develops 2D and 3D images.

Typical scans include thousands of measurements. Typical x-ray scanning equipment has a dimensional accuracy and repeatability of 25 microns.

The major advantage of x-ray scanning is that the specimen's internal configurations can be measured and analyzed without disassembly. Additionally, x-ray scanning can be used as a method of NDE for new items and an aid in failure analysis for previously installed items. This method could also be used in receipt inspection to verify fit tolerances, defects, and welds of incoming items. Operation of the x-ray computer scanning system requires extensive training in use of the system as well as radiation safety.

9.3 X-Ray Fluorescence Spectrometer

An X-ray fluorescence (XRF) spectrometer is an x-ray instrument used for routine, relatively nondestructive chemical analyses of materials.

9.4 Contact Computer Scanning

Contact computer scanning is a technology based upon physical contact of the specimen by a probe. This technology is a mature process and is commonly performed using CMMs. The probe moves in a continuous path in all planes (x, y, and z), making physical contact with the specimen at predetermined or preprogrammed intervals. The probe repeats the process until a sufficient number of data points have been collected. The data are then digitized and converted into information suitable for use in a CAD/CAM environment for either manufacturing or drawing development.

Typical accuracy and repeatability of the system are 0.035 and 0.001 millimeters, respectively. Special training is required to operate the system, but it is not as complex as the x-ray scanning system. The system requires a special foundation and environmentally controlled work areas to function effectively.

The above scanning technologies can also be used to measure key dimensions to support acceptance testing and incoming receipt inspections of reverse-engineered items.

9.5 Additive Manufacturing (3D Printing)

One other system being used extensively in reverse engineering is additive manufacturing, commonly referred to as 3D printing. 3D printing uses a CAD drawing, perhaps developed from one of the preceding scanning methods, to create a solid item. Certain items, such as ceramic parts used for connectors and certain types of metal items, can be printed directly. When direct printing is not possible, the technologies can be applied to create wax models that can be used to quickly produce items such as pump impellers using an investment casting process to print sand molds for casting, using a negative of a solid model, and to create standard patterns that can be used to produce multiple parts via traditional sand casting production.

There are several types of 3D printing technologies available today including stereolithography, fused deposition modeling (FDM), and direct-metal laser sintering (DMLS). These various methodologies use differing materials and fabricating methods to produce a model that can be used to determine fits and tolerances and to verify dimensions of reverse-engineered items prior to issuing a fabrication order. Depending on the final use and material requirements, the 3D printed part may or may not be suitable for use in the field.

Stereolithography uses a fine laser beam projected onto the surface of a vat of photocurable polymer. The laser beam moves slowly over the material constructing the reverse-engineered item layer-by-layer, from the bottom up, until the complete 3D specimen has been constructed. The material is then removed and cured.

Stereolithography will not produce an item with the fine tolerances that could be obtained by machining or precision grinding. However, the cured model can be further machined and ground to obtain tolerances within 0.005 inch.

FDM is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. FDM works on an “additive” principle by laying down material in layers; a plastic- or carbon-fiber filament or metal wire is unwound from a coil and supplies material to produce a part. Additionally, FDM technology 3D printers can be used to print sand casting molds and cores that can be used to create metal castings with molten metal.

DMLS is an additive manufacturing technique that uses a laser fired into a bed of powdered metal; the laser is automatically aimed at points in space defined by a 3-D model, welding the material together to create a solid metal structure. Very little validation and testing has been performed to date on using DMLS and other metal 3D-printed parts in a nuclear power facility. However, this technology does promise to provide printed metal parts that can be as strong and materially consistent with metal pieces produced using more conventional methods.

Depending on the size, complexity of the part and material type, and 3D printing method, the average model takes from 4 to 12 hours to produce. Some systems are automatic and could be programmed to run overnight or over a weekend.

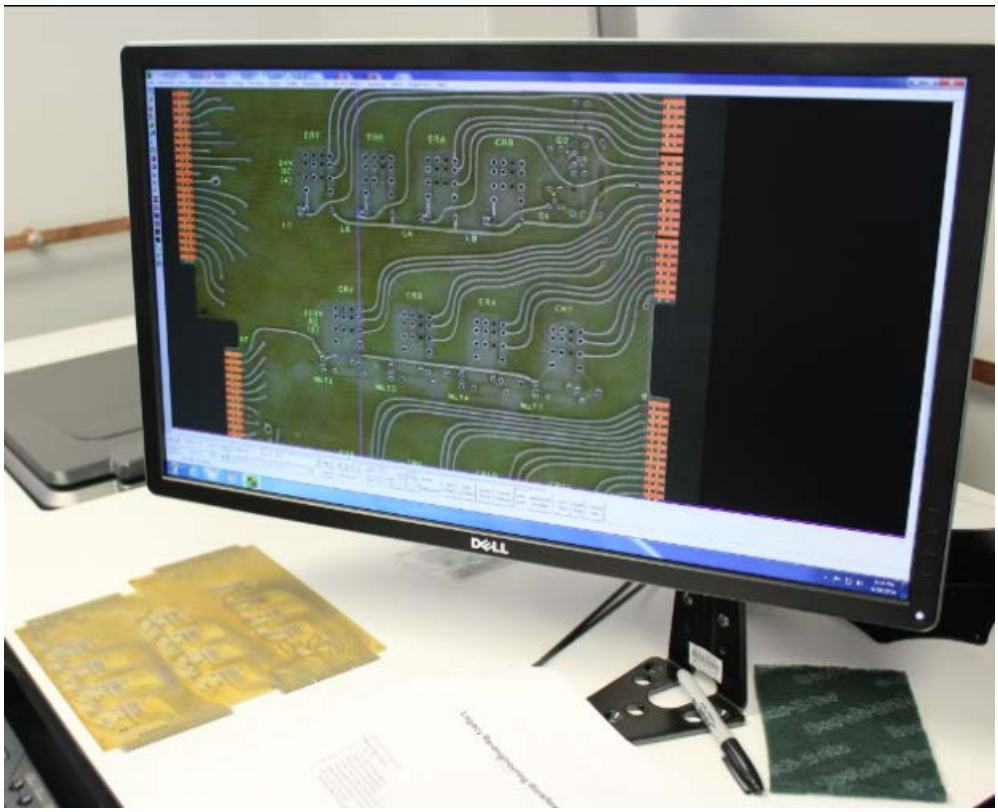


Figure 9-5
A Printed Circuit Board and the Image Captured Using ScanCad International ScanFAB at NextEra Energy, Incorporated

9.6 Printed Circuit Boards

There are some specific technologies that are used in the reverse engineering of printed circuit boards (PCBs). Equipment needed for this process is a scanner that will record each layer and its characteristics and a delamination machine (media blaster) that will precisely remove each layer of an unpopulated circuit board.

A flatbed scanner system has the capability of scanning PCBs, film, stencils, drawings, etc., to produce all the necessary data to re-manufacture a multi-layer PCB. The scanner uses an editor that can be used to create/modify the Gerber data that includes the layout and design of the individual layers of the PCB. Figure 9-5 shows an image captured through scanning a circuit card.

The high-resolution scanner is calibrated with a National Institute of Standards and Technology- (NIST-) traceable glass plate, ensuring an accurate image of the scanned film, stencil, or PCB. The color scanning capability of the scanner and the powerful color separation software algorithms in the system permit the fast and easy color separation of images needed to vectorize multilayer PCBs. The system also includes a raster filter and clean up and editing features to help massage the raster data prior to vectorization.

Another technology used in the reverse engineering of PCBs is automated testing using robotic test fixtures. This allows for repeatability and accuracy of inspection, measurements, and testing to ensure that reverse-engineered PCBs match the electrical and mechanical requirements of the original board.



Figure 9-6
An Automated Circuit Card Prober Used by NextEra Energy, Incorporated

The Huntron Access DH circuit card prober shown in Figure 9-6 is an example of a system that can collect readings between every two points on a circuit card while the card is energized, capturing the information necessary to duplicate the card's architecture and functionality. Manual examination and measurement of a circuit card can also be used to capture design information as illustrated in Figure 9-7.



Figure 9-7
A Technician at NextEra Energy, Incorporated, Analyzing a Circuit Card Used in Wind Turbines

When using the new technologies and systems discussed, it is important to ensure repeatability in the process. Each measurement/scanning machine should be stored in a controlled environment and be controlled through regular maintenance and calibration programs and standards such as International Standards Organization (ISO) or NIST. As these tools and technologies evolve, the accuracy and repeatability is consistently getting better. Many of the items that are being reverse engineered today were originally manufactured using older technologies, methods, and tools. These older parts may have been designed with wider tolerance ranges and methods that were not as consistently repeatable from lot to lot.

10
TABLETOP EXAMPLES

Provided in this section are typical examples of the use of reverse-engineering techniques. These examples are actual case studies from nuclear utilities and suppliers with reverse-engineering experience. The examples follow the reverse-engineering process as depicted in Section 4 of this report and suggest a success path for implementing the processes contained herein.

It should be noted that for more complex items being reverse engineered, the process may require more iterations between the activities described in Steps 4.1, 4.2, and 4.3.

10.1 Resistance Temperature Detector

This example discusses how reverse-engineering techniques are applied by a supplier to facilitate replacement of a resistance temperature detector (RTD) assembly that includes a thermowell similar to the image in Figure 10-1.



Figure 10-1
RTD and Thermowell Assembly (Photo courtesy of United Controls International)

Description

The RTD is used on a chiller and is obsolete with no surplus replacements available. The RTD has a very specific temperature/resistance point that has to be met, 560 ohms @ 74.3°F with an accuracy of ± 4%. Any change to this parameter would require modification to the chiller control circuit. discussions with the licensee, it was learned that the other critical parameter that has to be maintained is the inserted dimension of the RTD, which is critical in order to maintain internal clearances. The installed environment is determined to be mild, and the RTD is determined to be seismically insensitive.

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The plant identifies that an RTD and thermowell for a chiller system are obsolete and are no longer available. The end use for the RTD and thermowell is to provide temperature feedback for a feedwater loop on a chiller system.
4.2.1	**Collect/review the design information** The part number and datasheets for the original RTD and thermowell are available. Datasheets include detailed dimensions, temperature vs. resistance curves, and dimensional/electrical tolerances. The licensee identifies the critical operating point as 560 ohms @ 74.3°F with an accuracy of ± 4%. For this use (Chiller for control room temperature), the operating point of 74.3°F is a steady state point, so response time was not considered to be critical for the RTD.
4.2.2	**Inspect, test, and measure the original** A previously installed specimen of the RTD and thermowell assembly is compared to the original item datasheet. Material, dimensions, and the temperature/resistance setpoint are confirmed. Materials are verified through material analysis, the dimensions are confirmed through thread gauges and micrometers, and the resistance vs. temperature characteristics are verified through functional testing.
4.2.3	**Review the operating experience** The RTD has a specific critical operating point that must be maintained so as not to change the overall system setpoint. No “off-the-shelf” RTDs or thermowells are identified that could meet this operating point or meet the insertion dimensional requirements. Since the original item is obsolete and no “off-the-shelf” replacement items could be identified, the decision is made to use reverse engineering to fabricate a replacement for the original item. A review by the licensee yields no pertinent OE for this type of device.
4.2.4	**Determine if enhancements are required** No changes are requested or determined to be required.
4.2.5	**Evaluate the applicable environmental conditions** As long as the electronics housing of the RTD and the thermowell materials do not change, no further environmental testing is required. The RTD is considered to be installed in a mild environment.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** It is determined that the insertion length of the thermowell and the pipe fitting are the critical dimensions that need to be maintained. External dimensions are determined not to be critical as there are no external dimensional constraints identified by the licensee. Additionally, the RTD temperature/resistance point (output) has to be 560 ohms @ 74.3°F with an accuracy of ± 4%.
4.2.7	**Plan the activities required to demonstrate function** A test plan to verify the functionality of the new RTD and thermowell is completed. The plan includes verification of critical dimensions, materials, and the resistance vs. temperature curve and setpoints.

Flowchart Step	Description
4.3	***Establish/vet the replacement item design***
4.3.1	**Determine if the design functions are known/supported?** Yes. The design function of the RTD and thermowell is to transmit a resistance back to the control system. The system is calibrated based on the RTD temperature vs. resistance curve. The operating point that is critical to the system function must be maintained.
4.3.2	**Determine if the in situ conditions are known/supported** Yes. The licensee provides the necessary in situ conditions. There are no known in situ conditions (for example, temperature, dose, etc.) that exceed the design inputs for the device. The licensee confirms that the RTD is installed in a mild environment. No requirement for a NEMA enclosure was included in the specification.
4.3.3	**Determine if unknown parameters have been identified and reconciled** Yes. No unknown parameters were identified. The original datasheets and an original installed specimen were both available for review and testing.
4.3.4	**Determine if interfaces been addressed** Yes. The same electric interface (termination style, number of wires, and so forth) for the electrical connections was used on both the original item and the reverse-engineered item. Dimensional interfaces such as the insertion length were addressed.
4.3.5	**Determine if tolerances been evaluated** Yes. Since the original datasheets are available, the tolerances for both dimensions and function of the RTD and thermowell were identified and can be used during the reverse engineering of the item.
4.3.6	**Determine if activities are sufficient activities to demonstrate functionality** Yes. The testing activities used to verify the functionality of the reverse-engineered RTD and thermowell are submitted and approved by the licensee.
4.3.7	**Complete the activities to demonstrate functionality** Testing is conducted to verify the functionality of the new RTD. Testing and inspection includes verification of critical dimensions, materials, and the resistance vs. temperature curve and setpoints.
4.3.8	**Finalize the reverse-engineering output** Drawings, procurement specifications, functional test plans, final test report, and so forth are completed by the supplier. These documents are submitted to the licensee for final review and approval.
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement item?** Yes. Reverse-engineering techniques were used to gather the dimensional, material, and functional requirements of the original RTD and thermowell. Based on these inputs, specifications were developed to facilitate manufacture of a custom-designed RTD and thermowell. The original datasheets were available along with a specimen. Results from testing and inspecting the specimen were evaluated. Dimensions, tolerances, materials, and functional characteristics were identified and provided to the customer for additional input. A new RTD and thermowell were designed to be equivalent to the original RTD and thermowell in terms of dimensions, materials, operation, and functionality.

Flowchart Step	Description
4.4.2	**Does the RE item require a change to the FSAR?** No. The RTD and thermowell are below the level of design detail found in the FSAR, as indicated by the licensee.
4.4.3	**Is an in situ engineering special test/inspection required?** No. Testing of the RTD and thermowell after installation is not required. Testing and inspection prior to shipment verified that dimensions, material, tolerances, and function were equivalent to the original devices and provided confidence that the RTD and thermowell would perform their function.
4.4.4	**Are new failure modes introduced?** No. There are no new failure modes introduced as the materials, critical dimensions, and electrical functionality of the item have not changed.
4.4.5	**Are Operations-critical document (OCD) updates required?** No. The licensee determined that the RTD and thermowell are not specifically discussed in any documents that Operations relies on to tag out equipment, place equipment in a safe condition, operate the host equipment safely, etc.
4.4.6	**Any changes to bounded technical requirements?** No. The licensee determined that there are no changes to bounded technical requirements.
4.4.7	**Is a review of equipment qualification required?** No. The RTD and thermowell are installed in a mild environment, and the materials of construction did not change; thus, there is no need for any new environmental testing or qualification.
4.4.8	**Could differences impact calculations?** No. No electrical differences were made, and the critical resistance vs. temperature setpoint and thermowell insertion length are maintained. Based on this, no calculations to the system function were impacted.
4.6	***Item equivalency evaluation*** Based on responses to Steps 4.4.1 through 4.4.8, a design engineering review was not required. Therefore, an item equivalency evaluation (4.6) was used by the licensee to control the design for the RTD and thermowell.

10.2 Complex Pressure-Retaining Mechanical Component

This example discusses how reverse-engineering techniques are applied by a supplier to facilitate replacement of a pressure-retaining component that requires the movement of a piston based upon a pressure differential between compressible and non-compressible fluids.

Description

This device is an example of a complex, mechanical reverse-engineered component. It involves a number of mechanical items that are assembled to perform a function in the host system. It consists of a cylinder, two end caps, a piston, and a variety of seals. The licensee requests that reverse-engineering techniques be used by a supplier to enable fabrication of a replacement to

reduce lead time. The supplier reviews the request and begins to determine if this project is in their scope of supply as well as if the licensee's intent for reverse engineering this component is feasible.

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The licensee issued a purchase order to the supplier to reverse engineer this pressure-retaining component. The only information initially provided was an OEM part number and purchase description. The supplier initiated communications with the licensee using an interface plan requesting design function, design inputs, design basis information, drawings, etc.
4.2.1	**Collect/review the design information** The licensee and the supplier applying reverse-engineering techniques work closely together to determine the information available and required. This information includes but may not be limited to; plant design documentation, system or component documentation, available original equipment specifications, publicly available information, vendor manuals, and maintenance procedures. The plan for the reverse engineering and design-related activities are established prior to the licensee supplying the specimen. This plan identifies all relevant information regarding the component including safety classification, host component or system, safety function, interface requirements, and any additional pertinent information. This plan also includes the deliverables and responsibilities of the licensee and the supplier. The prototype development and design activities would be defined as well. Because this is an iterative process, this plan may be revised to include new information or additional requirements as identified.
4.2.2	**Inspect, test, and measure the original** An unused spare component is submitted for reverse-engineering service by the licensee. Upon receipt, visual and dimensional inspection of the component is performed, noting any labels or markings. Since design parameters and performance requirements have been identified by the licensee, performing functional testing on the specimen item is not required in order to develop baseline requirements. The specimen component is disassembled to evaluate each subcomponent to determine the following design characteristics: • Chemical and physical properties of the materials for each of the subcomponents • Dimensions for all subcomponents • Plating and other types of surface treatment Complete visual, dimensional, material (chemistry and condition), and plating analysis is performed for each part. All dimensional features are documented for the evaluation, including assessment of the tolerances. Similarly, the material and plating are also to be included in the evaluation. Drawings for each item and assembly are created based on the evaluation analysis. Each item is fully defined from a dimensional, material, and plating perspective. Any industry standards for dimensional or material aspects are reviewed and incorporated, as applicable. Based on an engineering review of the end use in the system, as well as development of the plan for the reverse engineering and qualification required for the component, the aforementioned design characteristics need to be addressed to ensure that the reverse-engineered item performs design functions under normal and accident design conditions.

Flowchart Step	Description
4.2.3	**Review the operating experience** The component historical information may be beneficial for reverse-engineering success. Understanding the evolution of the component may provide insight into how the item has been changed or modified since the initial design to improve performance or reliability. In some cases, poor design may be detrimental to the reverse-engineered component in replicating these poor design characteristics. The supplier is not able to access any OE about the component; however, the licensee communicates relevant OE about corrosion and plating delamination that occurred inside the device. In the case of this pressure-retaining component, it is discovered that a material change had been made by the OEM in order to address the OE and to improve the reliability of the component. The OE is vital information in ensuring that the reverse engineering is being performed in accordance with the most current design of the component. OE is discussed with the licensee to communicate impact on the final design developed using reverse-engineering techniques.
4.2.4	**Determine if enhancements are required** In this case, no additional changes are requested or required by the licensee or indicated in operating experience.
4.2.5	**Evaluate the applicable environmental conditions** In situ environmental conditions (for example, temperatures, pressure, radiation, etc.) are requested from and provided by the licensee for use in evaluating the final design.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** Interfacing items within the device are to be assessed for fit such as the piston and inner wall of the cylinder because this affects the seal and overall performance. The overall length and outer diameter must also be evaluated in order to ensure proper fit with other components in the host system. Therefore, it is determined that dimensional/mechanical tolerances are important design characteristics.
4.2.7	**Plan the activities required to demonstrate function** Fabrication and testing of a prototype are planned to establish functionality of the device and interfacing parts under the range of plant conditions provided by the licensee. At this point, the following activities are anticipated to be performed: • Preliminarily develop the information necessary for prototype testing and successful procurement • Develop a prototype • Perform seismic analysis on the component • Conduct performance testing of the component
4.3	***Establish/vet the replacement item design***
4.3.1	**Are the plant design functions known/supported?** Yes. The device's end use and functions were provided by the licensee. The component has two primary functions: one is to maintain pressure boundary integrity, and the other is to transmit motive force from stored energy (upon actuation) in the form of pressurized nitrogen to a piston that applies force to process fluid.

Flowchart Step	Description
4.3.2	**Are the in situ conditions known/supported?** Yes. The licensee provides the necessary in situ conditions. There are no known in situ conditions that exceed the design inputs for the device (for example, temperature, dose, etc.).
4.3.3	**Have unknown parameters been identified and reconciled?** No unknown parameters identified. Use of reverse-engineering techniques and analysis enable determination of materials and dimensions. Since the original tolerances are unknown, appropriate tolerances are determined using the techniques described in Section 8 of this report that were originally included in EPRI TR-107372, *Guideline for Reverse Engineering at Nuclear Power Plants* [1].
4.3.4	**Determine if interfaces are addressed** Yes. The device's interfaces are addressed and are included in the technical evaluation and will be verified via prototype testing and analysis.
4.3.5	**Determine if tolerances are evaluated** Yes. Original machining processes are determined based on surface finishes present in the specimen. Tolerances are determined based on known accuracy and tolerance ranges for the original machining processes. Conclusions are documented in the reverse-engineered design and associated technical evaluation.
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes. The fabrication and successful testing of a prototype will confirm that tolerances are appropriate. Functional testing of the prototype at temperatures simulating in situ conditions demonstrates functionality of the device in the host system. Engineering analysis is used to establish the suitability of non-metallic materials as well as the structural integrity of the pressure vessel for use in the operating environment.
4.3.7	**Complete the activities to demonstrate functionality** Functional testing of the prototype is conducted at temperatures simulating in situ conditions to demonstrate functionality of the device in the host system. Testing verifies performance requirements and parameters identified by the licensee are met.
4.3.8	**Finalize the reverse-engineering output** Documents such as specifications, drawings, test plans, and others are completed by the supplier and provided to the licensee for a final review and approval.
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement?** Yes. Reverse-engineering techniques are used to develop a basis for the component design and fabrication of a replacement.
4.4.2	**Does the RE item require a change to the FSAR?** No. The licensee determined that since there is no change in design, the FSAR is not affected.

Flowchart Step	Description
4.4.3	**Is an in situ engineering special test/inspection required?** No. The licensee determined that testing after installation in the plant is not required to complete reverse-engineering activities.
4.4.4	**Are new failure modes introduced?** No. Final review and approval of the RE design by the licensee did not identify any new failure modes for the device.
4.4.5	**Are Operations-critical document (OCD) updates required?** No. Final review and approval of the reverse-engineered design by the licensee did not identify the need to change any operations-critical documents.
4.4.6	**Any changes to bounded technical requirements?** No. Final review and approval of the reverse-engineered design by the licensee did not identify changes to bounded technical requirements.
4.4.7/4.7	**Is a review of equipment qualification required?** Yes. The supplier used analysis to demonstrate that qualification is maintained by using the same materials used in the original devices for items subject to degradation. This analysis was evaluated and accepted in accordance with the licensee's engineering processes. Based on the licensee review, evaluation of the replacement item under an equivalency process was allowed to continue.
4.4.8	**Could differences impact calculations?** No. There are no changes made to the device that warranted a change to calculations.
4.6	***Item equivalency evaluation*** Based on the responses to Steps 4.4.1 through 4.4.8, a design engineering review was required for the new seismic analysis (4.4.7/4.7).
4.7	***Design engineering review*** Design engineering determined that a design change was not required. Therefore, an item equivalency evaluation (4.6) was used to control design of the plant for the component.

10.3 Valve Stem

This example discusses how reverse-engineering techniques are applied by a supplier for the replacement of a valve stem.

Description

A valve stem is an example of a simple mechanical item. In this example, the licensee has requested that reverse-engineering techniques be used to facilitate the fabrication of a replacement valve stem for a valve that is obsolete. The supplier who is performing the reverse engineering has reviewed the request and begins to determine if this project is feasible. The safety-related stem is used in a control valve to isolate flow and is shown in Figure 10-2.



Figure 10-2
Valve Stem (Photo courtesy of Curtiss-Wright Nuclear Division)

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The licensee supplies known design information regarding the application. In this case, the end use is a safety-related control valve that controls flow.
4.2	***Identify the original item's design characteristics***
4.2.1	**Collect/review the design information** The stem transmits actuator movement/force to the valve disc to control flow through the host valves. The stem material (ASTM A 582 Type 416 Condition A) was also recovered in this step from documents in possession of the licensee (assembly drawing, CMTRs from previously purchased stems, etc.)
4.2.2	**Inspect, test, and measure the original** The supplier uses modern metrology to define the mechanical properties of the stem. Material and dimensional information is recovered from the specimen provided. The dimensions are captured using thread gauges, micrometers, and a CMM. Chemistry is verified via an X-ray fluorescence analyzer. Surface finish is measured, and mechanical properties are identified. The data are documented in both tables and a manufacturing print.
4.2.3	**Review the operating experience** The licensee researches available OE regarding the stem and informs the supplier that there is no relevant applicable OE.
4.2.4	**Determine if enhancements are required** In this case, no changes are requested or required.

Flowchart Step	Description
4.2.5	**Evaluate the applicable environmental conditions** The stem does not require any environmental qualification.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** Fit and tolerances are considered via application knowledge and inspection output. Tolerances are assigned based on feature type and are assigned conservatively; therefore, tighter than typical OEM tolerances. A production print is created, and the associated support documentation provides justification for each of the stem's attributes and assigned values.
4.2.7	**Plan the activities required to demonstrate function** Testing is not required to establish function as the function is known and there are no changes to the design of the stem. The material used to fabricate the stem and dimensions will be controlled under a 10CFR50, Appendix B-compliant QA program.
4.3	***Establish/vet the replacement item design***
4.3.1	**Determine if the design functions are known/supported** Yes. The design function of the stem is to transmit actuator movement/force to the disc. The stem will perform this function assuming that it is manufactured from the same material, dimensions, and surface finish of the original. The stem itself contains all the features assigned in the original design to achieve that function, and this information is recovered and documented during the inspection process.
4.3.2	**Determine if the in situ conditions are known/supported** Yes. The licensee provides the necessary in situ conditions. There are no known in situ conditions that exceed the design inputs for the stem.
4.3.3	**Determine if unknown parameters have been identified and reconciled** Yes. No unknown parameters were identified. Use of reverse-engineering techniques and analysis enable the determination of materials and dimensions.
4.3.4	**Determine if interfaces are addressed** Yes. Strict adherence to re-creating design characteristics and assignment of conservative tolerances ensure appropriate fits with interfacing parts.
4.3.5	**Determine if tolerances are evaluated** Yes. Original machining processes are determined based on surface finishes present in the specimen. Tolerances are determined based on known accuracy and tolerance ranges for the original machining processes. Conclusions are documented in the reverse-engineered design and associated technical evaluation.
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes. Inspection against manufacturing prints will adequately demonstrate the functionality of the stem.
4.3.7	**Complete the activities to demonstrate functionality** Material used to fabricate the stem is controlled under a 10CFR50, Appendix B-compliant QA program. Dimensional inspection to ensure that the stem conforms to the manufacturing prints is performed.

Flowchart Step	Description
4.3.8	**Finalize the reverse-engineering output** Documents such as drawings, inspection plan, and so forth are completed, reviewed, and approved in accordance with the supplier's procedures.
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement?** Yes. Reverse-engineering techniques were used to recover design information about the stem design to enable the development of design information that was submitted to the customer for approval and used to fabricate a replacement after approval.
4.4.2	**Does the RE item require a change to the FSAR?** No. The licensee determined that the stem is below the level of design detail found in the FSAR.
4.4.3	**Is an in situ engineering special test/inspection required?** No. Testing of the stem after installation is not required. Examination and measurement included in the final inspection plan provide confidence that the stem will perform its function.
4.4.4	**Are new failure modes introduced?** No. The licensee determined that no new failure modes are introduced.
4.4.5	**Are operations-critical document (OCD) updates required?** No. The licensee determined that stem is not specifically discussed in any documents that operations relies on to tag out equipment, place equipment in a safe condition, operate the host equipment safely, etc.
4.4.6	**Any changes to bounded technical requirements?** No. The licensee determined that there are no changes to the bounded technical requirements.
4.4.7	**Is a review of equipment qualification required?** No. The stem does not require any qualification as the host equipment is not qualified.
4.4.8	**Could differences impact calculations?** No. The licensee determined that no calculations are affected.
4.6	***Item equivalency evaluation*** Based on the responses to Steps 4.4.1 through 4.4.8, a design engineering review was not required. Therefore, an item equivalency evaluation (4.6) was used to control the design for the stem.

10.4 Pipe Plug

This example discusses how reverse-engineering techniques are applied by a licensee to replace a pipe plug that is no longer available from the original supplier of the host equipment.

Description

A pipe plug intended for installation on an air-operated valve is required for an upcoming outage. The pipe plug was originally supplied by the OEM of the valve and was stocked under the OEM part number and the simple description "stainless steel plug." The part number and description were taken directly from the OEM's bill of material. A typical pipe plug is illustrated in Figure 10-3.

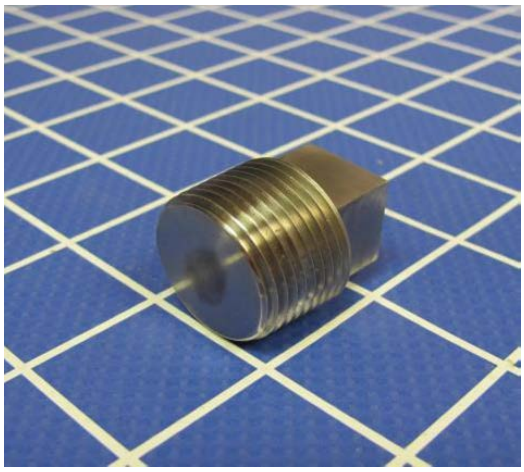


Figure 10-3
Typical Pipe Plug (Photo courtesy of Curtiss-Wright Nuclear Division)

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** Issue history and current demands in the plant inventory system indicate that this pipe plug is used to plug a port in an actuator that is opened on occasion for maintenance and testing. Reverse-engineering techniques will be used to enable specification of a replacement since the OEM considers the original part number obsolete. The plug functions to maintain pressure integrity. The host actuator assembly is environmentally qualified. The qualification report makes no reference to the pipe plug.
4.2.1	**Collect/review the design information** No information is available other than the OEM description and part number. Review past purchase orders; the OEM's maintenance manuals, drawings, and the licensee's original actuator specification provide no further information.
4.2.2	**Inspect, test, and measure the original** The single plug remaining in stock is provided to the licensee's dedication facility for inspection, testing, and measurement. Thread gauges reveal the pipe threads are consistent with 0.25" nominal pipe size. Material analysis shows the plug is stainless steel consistent with ASTM A-182 [36] (fittings machined from bar) and dimensions indicate conformance with dimensions for a 0.25" nominal pipe size threaded pipe plug in ANSI B16.11, Forged Fittings, Socket Welded and Threaded) [36].
4.2.3	**Review the operating experience** The licensee researches available OE regarding both the pipe plug and the actuator, and finds no relevant OE.

Flowchart Step	Description
4.2.4	**Determine if enhancements are required** In this case, no changes are required.
4.2.5	**Evaluate the applicable environmental conditions** The licensee determines that the pipe plug does not impact the environmental qualification of the host components because it is not subject to degradation due to harsh environmental conditions that could occur following a loss-of-coolant accident.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** The licensee determines that the pipe plug can be described as meeting the dimensional requirements of ANSI B16.11 [37].
4.2.7	**Plan the activities required to demonstrate function** Testing is not required to establish function as the function is known and there are no changes requested.
4.3	***Establish/vet the reverse-engineered item's design***
4.3.1	**Determine if the design functions are known/supported** Yes. The function of the pipe plug is to maintain pressure integrity. The plug is a simple metallic item with no moving parts.
4.3.2	**Determine if the in situ conditions are known/supported** Yes. There are no known in situ conditions that exceed the design of the plug.
4.3.3	**Determine if unknown parameters have been identified and reconciled** Yes. No unknown parameters were identified. Use of reverse-engineering techniques and analysis enable a determination of materials and dimensions.
4.3.4	**Determine if interfaces are addressed** Yes. Interfaces are addressed because the item will be machined in accordance with ANSI B-16.11, Forged Fittings, Socket Welded and Threaded [37].
4.3.5	**Determine if tolerances are evaluated** Yes. Tolerances are based on ANSI B-16.11, Forged Fittings, Socket Welded and Threaded [37].
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes. Inspection against the information provided in the ANSI standard will adequately demonstrate the functionality of the pipe plug.
4.3.7	**Complete the activities to demonstrate functionality** Procurement and acceptance of the plug is controlled under the licensee's 10CFR50, Appendix B-compliant QA program to ensure that it conforms to material and dimensional standards.
4.3.8	**Finalize the reverse-engineering output** The description of the pipe plug is updated in the licensee's materials management system to reflect the material and dimensional specifications.

Flowchart Step	Description
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement item?** No. RE techniques were implemented to recover sufficient design information about the pipe plug to facilitate procurement of the item from an alternate supplier.
4.5	***Procurement evaluation*** A procurement evaluation was completed by the licensee to ensure that the item's design information was incorporated into the existing technical procurement requirements.

10.5 Control Relay

This example discusses how reverse-engineering techniques are applied by a supplier to replace a control relay similar to the one in Figure 10-4 that is no longer available from the original supplier.

Description

In this example, the supplier used reverse-engineering techniques to provide replacements for an entire series of obsolete relays. The supplier intends to market and furnish the resulting control relays as generic replacements.



Figure 10-4
Control Relay (Photo courtesy of United Controls International)

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** End-use applications and functions were not identified because the reverse-engineering techniques were initiated by a supplier and not a licensee. This was acceptable because the supplier's intent was to maintain configuration, function, and qualification of an existing product line.
4.2	***Identify the original item's design characteristics***
4.2.1	**Collect/review the design information** The published information on the relay consists of OEM sales brochures, catalog pages, and specification/installation sheets typically shipped with the relay. These documents provide some of the information needed to recover design data including the coil voltages, contact ratings, contact configurations, and nominal dimensions.
4.2.2	**Inspect, test, and measure the original** Specimens were obtained by the supplier for inspection, testing, and measurement. The supplier performed functional testing with the relay and socket specimens, which demonstrated relay functionality, and identified characteristics that were not revealed in the product specifications and literature.
4.2.3	**Review the operating experience** The sources of OE included 10CFR21 bulletins, interviews with affected licensees, and other publicly-available information regarding the product line of relays. The licensee reviewed OE and found no pertinent information.
4.2.4	**Determine if enhancements are required** The supplier solicits feedback from licensees and determines that two enhancements are appropriate. The handle used for pulling the relay out of the socket is not durable enough; therefore, a stronger material is selected and the shape/dimensions of the handle are changed. The durability of the cover is enhanced by using a polycarbonate material.
4.2.5	**Evaluate the applicable environmental conditions** A bounding environmental profile is developed to encompass original qualification levels. This included temperature, pressure, thermal-aging, seismic and accident conditions.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** The interface between the specimen relays and sockets are evaluated. Functional tolerances were evaluated using the relay catalog sheets and other available technical literature.
4.2.7	**Plan the activities required to demonstrate function** Fabrication and testing of a prototype are planned to establish functionality of the device. At this point, the following activities are expected to be performed: • Test, as needed, individual piece-parts after the disassembly of the specimens • Develop preliminary information necessary for prototype testing • Develop the prototype • Establish seismic and environmental qualification • Test the performance of the prototype

Flowchart Step	Description
4.3	***Establish/vet the replacement item design***
4.3.1	**Determine if the design functions are known/supported?** Yes. They are based on maintaining the original qualification.
4.3.2	**Determine if the in situ conditions are known/supported** No. The licensee is responsible for ensuring that their in situ conditions are addressed in the new qualification report. Since in situ conditions cannot be determined, the supplier will proceed to step 4.3.9, but decided to consider steps 4.3.3 through 4.3.5 before proceeding to step 4.3.9.
4.3.3	**Determine if unknown parameters have been identified and reconciled** Yes. The supplier identified characteristics that were not revealed in the product specifications and literature, and those characteristics are reconciled in the replacement item specification.
4.3.4	**Determine if interfaces are addressed** Yes. The device's interfaces are addressed and are included in the supplier's technical evaluation. They will be verified via prototype testing and analysis.
4.3.5	**Determine if tolerances are evaluated** Yes. Since the original datasheets are available to the supplier, the tolerances for both dimensions and function are identified and can be used during the reverse engineering of the relay.
4.3.9	**Generic or specific application?** The supplier is undertaking reverse engineering to provide a generic replacement for this obsolete line of relays.
4.3.10	**Verify suitability of the design** The supplier performs a preliminary design review and determines that the design is ready for prototyping. It is determined to initially proceed with some 3-D printed enclosures to test the fit-up before committing to having a mold made. Prototype parts are purchased and testing begins. Draft copies of the functional and type testing procedures are used during the prototype testing phase. This not only tests the relays, but it also allows for validating the test procedures. A second iteration of the prototype is used to correct issues identified during the initial prototype testing (for example, the contact alignment and fit in the socket are not correct). After the prototype relays are validated to function appropriately, a post-prototyping design review is completed by the supplier who determines that the reverse-engineered design is ready for qualification.
4.3.7	**Complete the activities to demonstrate functionality** Testing of the prototype is conducted to establish functional performance, seismic, and environmental qualification. As part of the qualification, the relay is shown to perform its design functions before, during, and after each qualification test. A final design review is completed to confirm successful qualification.
4.3.8	**Finalize the reverse-engineering output** The reverse-engineered relay specifications are updated with the information acquired during prototype testing. The test plan is also updated. The supplier finalizes specification sheets that include information about the relay's design including equipment qualification parameters.

Flowchart Step	Description
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement item?** Yes. Reverse-engineering techniques were used by the supplier to develop a basis for the component design and fabrication of a generic replacement for the control relay.
4.4.2	**Does the RE item require a change to the FSAR?** Not anticipated, because the control relay is typically below the level of design detail found in the FSAR. However, this would have to be evaluated by each licensee prior to accepting the relay for use.
4.4.3	**Is an in situ engineering special test/inspection required?** Not anticipated, but each licensee would have to determine the adequacy of qualification testing performed by the supplier and determine if any additional testing after installation is required.
4.4.4	**Are new failure modes introduced?** No. Final review and approval of the RE design by the supplier did not identify any new failure modes for the device. Licenses would need to confirm the relay is compatible with intended applications prior to accepting it for use.
4.4.5	**Are Operations-critical document (OCD) updates required?** Not anticipated, but each licensee would have to review drawings, documents, and program impacts to confirm that no OCD updates would be required.
4.4.6	**Any changes to bounded technical requirements?** Not anticipated, because the supplier envelopes the original qualification conditions to establish the requirements for qualification. However, system interface conditions (for example, bus voltage range, etc.) would have to be evaluated by each licensee.
4.4.7/4.7	**Is a review of equipment qualification required?** Yes. The licensee will evaluate the qualification performed by the supplier (Step 4.7) to verify that qualification is maintained in accordance with the licensee's procedures.
4.4.8	**Could differences impact calculations?** Not anticipated. There are no changes made to the device that warrant a change to any licensee calculations. However, this would have to be evaluated by each licensee.
4.6 or 4.8	***Item equivalency evaluation or a design equivalent change or design change*** Based on the responses to Steps 4.4.1 through 4.4.8, a design engineering review by the licensee (4.7) would be to determine acceptability of the new seismic and environmental qualification would be required. Design engineering review (4.4.7) will determine if an item equivalency evaluation (4.6), a design equivalent change, or a design change (4.8) is used to control design.

10.6 Fire Protection Panel

Description

This example includes the replacement of an obsolete fire protection subsystem shown being tested in Figure 10-5. The OEM is no longer in business, and surplus modules are no longer available. As a result, the licensee has had to take compensatory actions such as establishing fire watches in response to false alarms. The licensee requests that supplier use reverse-engineering techniques to facilitate replacement of system components.



Figure 10-5
Acceptance Testing of Fire Protection Panel and Associated Detectors
(Photo courtesy of Dynamic Solutions USA, Incorporated)

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The project scope included a total of 77 panels that provide monitoring and supervision of both single-zone and dual-zone indication and alarm circuits. The modules (building blocks) of the panel consisted of: • Control board module • Switch board module • Light emitting diode (LED) board module • D1 board module • Universal motherboard module • Two-zone initiating board module • Constant current board module • Auxiliary relay board module • Brownout board module The modules communicate between zones and the control room for indication and alarm functions.

Flowchart Step	Description
4.2	***Identify the original item's design characteristics***
4.2.1	**Collect/review the design information** The supplier visited the plant and performed walkdowns of in situ conditions and the configuration of the various fire protection panels. In addition, the supplier met with key stakeholders in Engineering, Instrumentation and Control (I&C), Maintenance, Document Control, and Supply Chain. This allowed the supplier to collect applicable technical manuals, data sheets, and operating historical test data, and to characterize the input/output and theory of operation of the chassis, power supplies, and modules within the project scope. The customer provided a known working chassis that was fully populated with all nine working modules to be evaluated at the supplier's facility.
4.2.2	**Inspect, test, and measure the original** The supplier used the design documentation and working specimens received from the customer to perform inspections on the panel components. Inspections included physical measurements of the modules, chassis, and power supply, and development of a relational parts list for each component. The supplier was able to duplicate field conditions by arranging the equipment to simulate a full system mockup under power with customer-provided detectors to characterize the overall system functions and individual inputs and outputs for each component. The supplier used this information to prepare a detailed acceptance test procedure (ATP) that would be used for functional testing and taking measurements intended for the prototype equipment to be manufactured (part of the planned acceptance activities). The ATP also included hold points for licensee QA source inspection at the supplier's facility.
4.2.3	**Review the operating experience** Internal OE reviewed, such as maintenance history indicates that failures were attributed to end-of-life aging and fatigue resulting from several repair cycles of panel components. History also indicates that the chassis and power supplies have a history of reliable performance.
4.2.4	**Determine if enhancements are required** Not applicable in this case.
4.2.5	**Evaluate the applicable environmental conditions** The original panel components were not seismically evaluated and are located in a mild environment according to the licensee requirements. The panels were classified as non-safety-related/augmented quality and had no environmental qualification requirements imposed under the contract.

Flowchart Step	Description
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** Due to the modular design, the component physical interface and mounting on the chassis is through individual module component connectors and mounting hardware. The individual module signal and functional characteristics were developed from Step 4.2.2 when the system equipment was simulated and the ATP developed. A summary of the module function by description was mapped as follows: 1. The control board module provides the primary interface for controlling system functions, monitors common system fault conditions, and supplies up to 4 amperes (amps) of signal power available for supervisory functions, battery charging, and controlling remote devices. 2. The switch board module provides the following switches: a. Acknowledge alarm – Operation of this switch will silence the alarm circuits that are activated during an alarm condition. b. Drill – Operation of this switch will sound all the system alarm circuits but will not affect the auxiliary, such as the master box. c. Alarm off – This switch silences all audible alarm devices connected to the system. d. Battery high-rate – This switch increases the battery charger voltage to the batteries. e. Trouble off – This locking switch silences system trouble tone and lights the trouble LED. f. Reset – This switch restores the system to normal and must be operated after alarm or trouble conditions have been cleared. g. City off – This switch disconnects any auxiliary alarm device (master box, polarity reversal unit) from the system. h. Lamp test – This switch lights all LEDs on the system except “power on” and the “city” LED. 3. The LED board module provides alarm indication. 4. The D1 board module provides processing of all audible alarm functions. 5. The universal motherboard module is a four-zone initiating circuit mother board. This module is compatible with a variety of two-zone daughter boards that power and detect two-wire ionization, photoelectronic, or a combination (ionization/photoelectronic) smoke detectors directly from the initializing circuit and will also accept normally open shorting devices on the same circuit. Up to five detectors can simultaneously alarm and perform local control functions. 6. The two-zone initiating board module is a two-zone alarm-initiating circuit. 7. The constant current board module provides battery monitoring and charging functions. (Hi-Rate current is programmable by on the constant current board to charge either at ½ amp for 5–20 ampere hour (AH) batteries or 1 amp for 20–40 AH batteries. 8. The auxiliary relay board module controls devices such as remote alarm and/or trouble annunciators. 9. The brownout board module controls the transfer of system power to battery power when the bridge voltage (input AC) goes too low for the regulator to maintain regulation.

Flowchart Step	Description
4.2.7	**Plan the activities required to demonstrate function** The supplier's reverse-engineering process requires the development of a quality plan that details elements of reverse-engineering activities, provides guidance on required testing, and includes a project schedule for manufacturing and testing of a testing prototype and production units of each module/component. The quality plan also addresses material production lot/date code requirements under the production controls framing the project, including witness and hold points for customer QA inspection. Functional verification with input/output response was identified in the applicable portions of the ATP developed for each module. The quality plan was submitted to the licensee for review and approval.
4.3	***Establish/vet the replacement item design***
4.3.1	**Determine if the design functions are known/supported** The supplier, with the assistance of the customer engineering staff, identified original design and functional attributes at both the system and module levels.
4.3.2	**Determine if the in situ conditions are known/supported** Yes. In situ conditions identified during the supplier walkdown are considered and supported by the replacement design.
4.3.3	**Determine if unknown parameters been identified and reconciled** Yes (no unknown parameters were identified).
4.3.4	**Determine if interfaces been addressed** Yes, interfaces are addressed by the ATP that included a mockup of the full system.
4.3.5	**Determine if tolerances been evaluated** Yes. The supplier recreated all new schematics, bills of materials, layouts, and fabrication drawings for each of the modules; dimensional and electrical tolerances were addressed in these documents.
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes, each module and panel had functional test plans developed and carried out to show functionality.
4.3.7	**Complete the activities to demonstrate functionality** 100% of the functionality of the nine module boards was established, tested for, and verified. a. As stated above, the nine module boards were connected to all the detectors to simulate installation in the plant. b. These 9 module boards then were tested in accordance with the ATP The module boards then were installed in the plant, energized, and monitored for a 27-day continuous run without any problems.
4.3.8	**Finalize the reverse-engineering output** The reverse-engineered units (both prototype and production units) were tested fully to verify all inputs and outputs, and the results of testing in all cases were consistent with the results of OEM specimen testing.

Flowchart Step	Description
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement item?** Yes. Reverse-engineering techniques were used to develop a replacement design.
4.4.2	**Does the RE item require a change to the FSAR?** No. The design of the components is below the level of design detail included in the FSAR.
4.4.3	**Is an in situ engineering special test/inspection required?** Yes, prototype testing was conducted as an in-process verification at the customer's facility using a portion of the system that was tagged out of service. In situ testing validated function and compatibility with existing maintenance procedures. A design engineering review (4.7) will be performed.
4.4.4	**Are new failure modes introduced?** No. The licensee determined that no new failure modes were introduced.
4.4.5	**Are Operations-critical document (OCD) updates required?** No. The licensee determined that no OCD updates were required.
4.4.6	**Any changes to bounded technical requirements?** No. The licensee determined that there were no changes to bounded technical requirements.
4.4.7	**Is a review of equipment qualification required?** No. These modules are classified as non-safety-related and have no equipment qualification requirements.
4.4.8	**Could differences impact calculations?** No. The licensee determined that no calculations were impacted.
4.7	**Design engineering review** The system was non-safety-related, and in situ testing of the prototype was controlled by Engineering and the Maintenance department as an in-process test, separate from screening activities to the appropriate implementation process. After prototype testing, the prototypes were removed and replaced with original equipment.
4.8	***A design equivalent change or design change?*** Due to the complexity involved in replacing the entire system, the customer would control the design for this replacement using a design equivalent change or a design change, depending upon their internal procedures and processes.

10.7 Ramp Generator and Signal Converter

Description

This example is of using reverse-engineering techniques to manufacture a replacement electrical component. The Woodward Ramp Generator and Signal Converter (RGSC) involves a steel enclosure (with graphics, markings, and lettering), an amplifier circuit board, and various components mounted on the enclosure (potentiometers, test jacks, insulated wire, hardware, and a terminal block). Figures 10-6 and 10-7 are images of the original OEM design. Figures 10-8 and 10-9 are images of the reverse-engineered design.



Figure 10-6
Woodward RGSC 9903-087 – Front
(Photo courtesy of Paragon Energy Solutions, LLC)

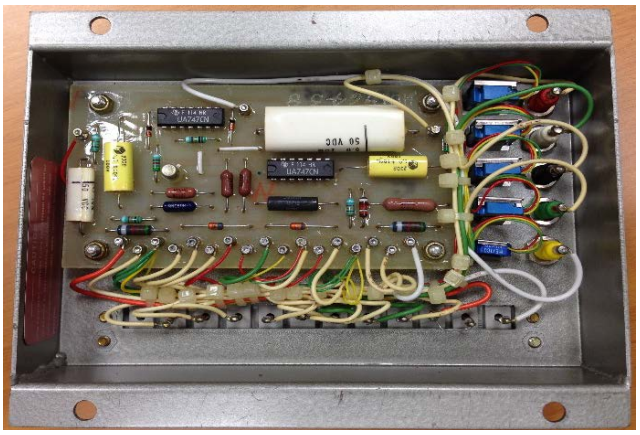


Figure 10-7
Woodward RGSC 9903-087 – Back
(Photo courtesy of Paragon Energy Solutions, LLC)



Figure 10-8
Reverse-Engineered First Article – Front
(Photo courtesy of Paragon Energy Solutions, LLC)

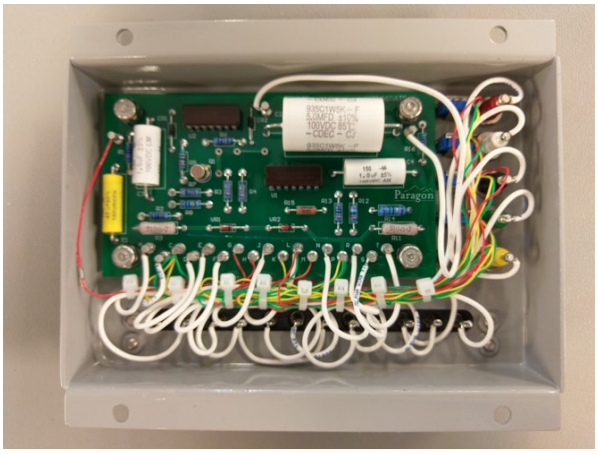


Figure 10-9
Reverse-Engineered First Article – Back
(Photo courtesy of Paragon Energy Solutions, LLC)

The licensee requests that reverse-engineering techniques be used by a supplier to enable fabrication of a replacement since the OEM does not support this product line anymore. The supplier reviews the request and begins to determine if this project is in their scope of supply and if the licensee's intent for reverse engineering this component is feasible.

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The licensee issued a purchase order to the supplier to reverse engineer this Woodward RGSC (P/N: 9903-087). Information initially provided was an OEM part number and purchase description. However, it was known that the supplier had previously reverse engineered similar Woodward RGSC components in the past and had a working knowledge of the unit's function through various repair/refurbishment activities. The supplier initiated communications with the licensee through email correspondence requesting design function, design inputs, design basis information, drawings, all pertinent OEM documentation, etc.
4.2	***Identify the original item's design characteristics***
4.2.1	**Collect/review the design information** The licensee and the supplier performing the reverse engineering worked closely together to determine the information available and required. This information included plant design documentation, system or component documentation, available original equipment specifications, publicly available information, vendor manuals, and maintenance procedures. Through correspondence with the licensee, it was determined that a specimen cannot be supplied to the supplier for their reverse-engineering activities. The licensee did not have enough spares to facilitate shipping a unit to the supplier for an extended period. It was determined that the supplier will travel to the licensee and spend time on site evaluating one of their spares, documenting all information required for the design activities. Once the site visit was completed, a detailed design management plan was developed to document all of the following in detail: • Safety function • Operating experience/Part 21 investigation • Re-engineering justification • Design approach (including the following): o Primary information for reverse engineering o Secondary information for reverse engineering o End use of product o Inspection/evaluation of specimen o Mechanical interfaces o Electrical interfaces o FMEA to determine critical characteristics for the design o Develop and test approach of RGSC prototype o Manufacture RGSC 9903-087/ATC

Flowchart Step	Description
4.2.1 (continued)	• Equipment qualification considerations • Workmanship • Design verification • Design maintenance • Authorities and responsibilities • Anticipated design documents • Communications and reporting Because this is an iterative process, this plan may be revised to include new information or additional requirements as identified.
4.2.2	**Inspect, test, and measure the original** An unused spare component was not submitted for reverse-engineering service by the licensee due to limited spares. The supplier coordinated an on-site visit to the licensee to inspect an available spare and gather all information available. This site visit lasted for about a week during which a subject matter expert in reverse engineering inspected the spare and documented all pertinent information. A detailed inspection was performed to record dimensions, parts installed on the board, part interfaces and connections. Detailed photographs were taken for engineering reference during the reverse-engineering process. Generic industry standards for Terry Turbine control systems were used to augment information provided by the customer and gathered during the site visit. Specific calibration parameters and testing instructions were supplied by the customer as applicable. Similar RGSC models previously reverse engineered by the supplier provided complimentary information during the reverse-engineering process.
4.2.3	**Review the operating experience** The component historical information may be beneficial for the reverse-engineering success. Understanding the evolution of the component may provide insight into how the item has been changed or modified since the initial design to improve performance or reliability. In some cases, poor design may be detrimental to the reverse-engineered component in replicating these poor design characteristics. The supplier performs a search of the NRC ADAMS database to determine if there are any Part 21 notifications regarding RGSC 9903-087. The search results in no notifications. As stated above the supplier has previous reverse-engineering experience with similar RGSCs of the same configuration, however, with a different part number and electrical characteristics. No additional operating experience was provided during the site visit.
4.2.4	**Determine if enhancements are required** In this case, no additional changes were requested or required by the licensee or indicated in the operating experience.

Flowchart Step	Description
4.2.5	**Evaluate the applicable environmental conditions** In situ environmental conditions (for example, temperature, pressure, radiation, etc.) were requested from and provided by the licensee for use in evaluating the final design. The licensee identifies that the reverse-engineered unit shall operate in a mild environment. The licensee defined the following temperature, relative humidity, and radiation parameters for a mild environment per IEEE 323-1974 [38]: Temperature: 0° Celsius (C) to 55.56°C (32°F to 132°F) Relative humidity: 20%--90% Radiation in RADS total ionizing dose (RADS TID): Less than 1 X 10^4 RADS TID In addition, the licensee specified a seismic required response spectra (RRS)
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** Interfacing items within the device were assessed for fit such as the mounting holes, locations of test points, and adjustable components. The overall dimensions must also be evaluated to ensure a proper fit at installation. Therefore, it is determined that dimensional/mechanical tolerances are important design characteristics. **Mechanical interfaces:** There are four mounting holes for the RGSC. **Electrical interfaces:** Electrical interfaces included five potentiometers, five test points, and a twelve-connection terminal block. The potentiometers are used to adjust the specific parameter settings required by the licensee. These five settings are Ramp Slope, Idle, Zero, Clamp, and Gain. The test points are used during calibration and other maintenance activities. The terminal block connections are as follows: Terminals 1–2: ±36 VDC supply Terminals 3–4: close to start ramp Terminals 5–6: 10–50 mA or 4–20 mA input Terminal 7: electric governor magnetic (EGM) summing point Terminal 8: 2301 summing point Terminal 9–10: jumper for 4–20 mA input Terminal 10–11: jumper for 10–50 mA input Terminal 12: spare

Flowchart Step	Description
4.2.6 (continued)	Reverse-engineering analyses identified the following attributes for the RGSC: Material of enclosure: cold-rolled steel Length of enclosure: 6.00 in ±0.03 in. Overall width of enclosure: 4.87 in. ±0.03 in. Box width of enclosure: 4.00 in. ±0.03 in. Overall height of enclosure: 1.41 in. ±0.03 in. Box height of enclosure: 1.00 in. ±0.03 in. Thickness of enclosure: 0.06 in. ±0.01 in. Total weight: 465 g. ±23 g. The overall mechanical design (that is, fit) is per the original OEM specifications, and measurements were taken from the specimen during the on-site visit. The supplier has manufactured similar enclosures, and applicable standards were utilized. There are no significant mechanical differences between different generations of Woodward Governor RGSC models. **Electrical inputs/outputs:** The RGSC is powered by an input voltage of 36 voltage direct current (VDC) ±2 VDC. This voltage and tolerance are defined by the OEM documentation and the applicable EPRI guideline. The outputs were verified through various calibration parameters as defined by the licensee. These calibration parameters were achieved through adjusting the applicable potentiometers (that is, Ramp Slope, Idle, Zero, Clamp, and Gain).

4.2.7	**Plan the activities required to demonstrate function**
	
	Fabrication and testing of a first article were planned to establish functionality of the device and the interfacing parts under the range of plant conditions provided by the licensee.
	
	At this point, the following activities were performed:
	
	• Applicable design documentation development to manufacture reverse-engineered units. These documents include, but are not limited to, the following:
	  o Bill of materials: Identifying all piece-part components required for manufacture
	  o Schematics: Identifying all electrical connections throughout the RGSC.
	  o Printed circuit board drawing
	  o Enclosure drawing
	• First article manufacture
	• First article acceptance testing
	  o Specific calibration parameters were provided by the licensee. The first article shall be tested by an acceptance test procedure that utilizes customer-specific calibration parameter input. If it is not provided by the customer, generic values defined by the applicable EPRI guidelines should be utilized as appropriate.
	  o Calibration parameters include idle voltage, zero voltage, gain voltage, ramp time, input current low, and input current high.
	• Seismic qualification of the first article through type testing/similarity analysis
	• Environmental qualification of the first article through type testing/similarity analysis

Flowchart Step	Description
4.3	***Establish/vet* the *reverse-engineered item's design***
4.3.1	**Determine if the design functions are known/supported (Identify the component end-use application and functions)** **Safety function (active):** The RGSC and electric governor magnetic (EGM) work together to control the speed of rotating machinery such as a large steam turbine. The RGSC module is designed to provide the EGM a voltage ramp at initial startup. **End-use application:** The RGSC is part of the control system used to control systems such as high-pressure coolant injection (HPCI) and reactor core isolation cooling (RCIC) steam turbines. It controls the acceleration of the turbines at a uniform rate through the EGM.
4.3.2	**Determine if the in situ conditions are known/supported** Yes, the licensee had provided the necessary in situ conditions as defined above. The ability of the reverse-engineered unit to withstand these conditions was demonstrated through either type testing or similarity analysis to another qualified RGSC of similar construction.
4.3.3	**Determine if unknown parameters have been identified and reconciled** No unknown parameters were identified.
4.3.4	**Determine if interfaces are addressed** Yes. The device's interfaces were addressed and were included in the technical evaluation and were verified via first article testing and analysis.
4.3.5	**Determine if tolerances are evaluated** Yes. Conclusions are documented in the RE design and associated technical evaluation.
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes. A test procedure is developed to simulate inputs and outputs at temperatures simulating in situ conditions so that functional testing can be performed on the first article to demonstrate functionality and tolerances as well as functionality of the device in the host system. Type testing of the first article is planned to verify structural integrity during a seismic event.
4.3.7	**Complete the activities to demonstrate functionality** Functional testing and type testing is successfully completed in accordance with the testing procedures.
4.3.8	**Finalize the reverse-engineering output** Documents such as schematics, bill of materials, outline drawing, acceptance test procedures, item equivalency evaluation, etc., were completed by the supplier and provided to the licensee for final review and approval.
4.4	***Determine* the *design control activity***
4.4.1	**Was RE used as a basis to design a replacement?** Yes. Reverse-engineering techniques were used to develop a basis for the component design and fabrication of a replacement.

Flowchart Step	Description
4.4.2	**Does the RE item require a change to the FSAR?** No. Since there is no change in design, the FSAR is not affected.
4.4.3	**Is an in situ engineering special test/inspection required?** No. Testing after installation in the plant is not required.
4.4.4	**Are new failure modes introduced?** No. Final review and approval of the RE design by the licensee did not identify any new failure modes for the device.
4.4.5	**Are Operations-critical document (OCD) updates required?** No. Final review and approval of the RE design by the licensee did not identify the need to change any operating critical documents.
4.4.6	**Any changes to bounded technical requirements?** No. Final review and approval of the RE design by the licensee did not identify changes to bounded technical requirements.
4.4.7/4.7	**Is a review of equipment qualification required?** No. Type testing was used to demonstrate that seismic qualification was maintained.
4.4.8	**Could differences impact calculations?** No. There are no changes made to the device that warranted a change to calculations.
4.6	***Item equivalency evaluation*** An item equivalency evaluation was used to control design of the reverse-engineered unit and was provided to the customer prior to production. This item equivalency evaluation included a piece-part by piece-part comparison.

10.8 Power Supply

This example discusses how reverse-engineering techniques are applied to facilitate manufacture of a replacement power supply that includes several enhancements requested by the customer.

Description

A customer requested the supplier to apply reverse-engineering techniques to facilitate replacement of a power supply for the Terry Turbine system and develop a replacement that is the same size and configuration as the specimen provided. However, the customer requested that the replacement include several different features and increased functionality. The changes were significant enough to require a new design and qualification. Figure 10-10 shows a finished replacement power supply.



Figure 10-10
Replacement Power Supply Designed Using Reverse-Engineering Techniques (Photo courtesy of AZZ Nuclear Engineered Solutions)

Flowchart Step	Description
4.1	**Identify the objectives, applications, and functions** The customer identified that they require a replacement for a Terry Corporation dual-output power supply that has the form and fit of NLI-890082B02-003, which is shown in Figure 10-10. However, the customer requests the following changes: • The power supply will not have an automatic shutdown feature. • The power supply can run continuously at 9 amps and can provide rated peak current (9 amps) under short circuit conditions on down-line circuits until the down-line fault is isolated. • The solder tabs on the terminal block should be removed.
4.2.1	**Collect/review the design information** The supplier consulted available data obtained through experience applying reverse-engineering techniques to similar power supplies. The supplier also worked with the customer to review available information and documentation including original vendor manuals, plant design documentation, system documentation, available original equipment specifications, and plant maintenance procedures. Although the customer could not provide a specimen, information such as dimensions, inputs, outputs, accuracy, and configuration was included in available documentation.
4.2.2	**Inspect, test, and measure the original** It was not possible to complete this step due to unavailability of a specimen.
4.2.3	**Review the operating experience** The supplier did an online search at nrc.gov that did not reveal any OE associated with defects or noncompliance of the power supply model and manufacturer. The customer had three specific configurations within their systems where this power supply is used. No “off-the-shelf” replacement items could be identified, so the decision was made to use reverse engineering to modify an existing design to meet their specific requirements.

Flowchart Step	Description
4.2.4	**Determine if enhancements are required** No enhancements were required other than the following requested by the customer: • The power supply will not have an automatic shutdown feature. • The power supply can run continuously at 9 amps and can provide rated peak current (9 amps) under short circuit conditions on down-line circuits until the down-line fault is isolated. • The solder tabs on the terminal block should be removed.
4.2.5	**Evaluate the applicable environmental conditions** The power supply is located in a mild environment, but it required seismic qualification in accordance with applicable Institute of Electrical and Electronic Engineers (IEEE) standards and original qualification reports provided by the customer. In addition, the power supply required EMI/RFI qualification.
4.2.6	**Evaluate the interfaces, fits, tolerances, inputs/outputs** It is determined that the external dimensions are critical and cannot be increased in any manner. All changes to the power supply must occur within the existing chassis design.
4.2.7	**Plan the activities required to demonstrate function** A test plan to verify the functionality of the replacement power supply was developed. In addition, first article testing was planned for two prototype units that included functional testing and verification of output response curves showing the supply going into a fault condition and recovery from the fault condition. Testing also was planned to verify that (1) when more than one fused circuit is fed from the power supply, the power supply internal fuse does not clear before the down-line fuses in the event of a down-line short circuit and that (2) the power supply meets the requirements of specific fuse coordination provided by the customer for three different scenarios based on the functional requirements associated with interfacing equipment. The standard test plan includes verification of critical dimensions and electrical characteristics.
4.3	**Establish/vet the replacement item design**
4.3.1	**Determine if the design functions are known/supported** Yes. The design function of the power supply is to provide regulated power to Class 1E loads. The customer provided end-use applications and functional requirements.
4.3.2	**Determine if in situ conditions are known/supported** Yes. The client provided the necessary in situ conditions. During review of the in situ conditions and prototyping of the board, it was determined that running the unit at peak current for an unlimited amount of time would result in the power supply heating up enough to trigger a thermal shutdown. Although the power supply is installed in a mild environment, there is not enough air flow to allow the power supply running at full power to be cooled via natural convection. After ongoing communication with the client informed by many hours of testing, it was determined that the client's requirements could be modified and that the power supply will work within the new parameters. The new parameters are that the power supply outputs an isolated 28 volts ± 5% at 3 amps (and up to 5.5 amps continuous) at a maximum operating temperature of 50°C/122°F The power supply will output at least 9 amps at 28 VDC for at least 10 minutes before the unit shuts down from thermal overload. During a short circuit or overload fault, the unit will fold back the voltage while continuing to supply at least 9 amps; in this mode with the lower output voltage, the unit can continue to operate beyond 10 minutes while supplying in excess of 9 amps. The input is from 100 to 150 VDC

Flowchart Step	Description
4.3.3	**Determine if unknown parameters have been identified and reconciled** Yes. Testing a prototype unit in conditions emulating the in situ environment identified thermal issues and allowed them to be resolved before the final design was completed.
4.3.4	**Determine if interfaces are addressed** Yes. The same electric interface for the electrical connections and mechanical mounting used on both the original item will be used on the reverse-engineered item.
4.3.5	**Determine if tolerances are evaluated** Yes. All tolerances were identified, evaluated, and approved by the client for the new power supply supported by the approved design basis, client's contractual requirements, and prototype testing.
4.3.6	**Determine if activities are sufficient to demonstrate functionality** Yes. The testing activities used to verify the functionality of the reverse-engineered item were submitted to the customer for review and were approved.
4.3.7	**Complete the activities to demonstrate functionality** Testing was conducted to verify the functionality of the new power supply. Testing and inspection includes verification of design characteristics including dimensions, electrical specifications, and output response/recovery.
4.3.8	**Finalize the reverse-engineering output** Drawings, functional test plans, procurement specification, etc., were completed by the supplier and submitted to the licensee for final review and approval. An updated documentation package including an instruction manual, theory of operation, drawings, testing and adjustment instructions, assembly drawings, a top-level schematic, parts list, and output derating curve (table) for temperature was provided to the customer.
4.4	***Determine the design control activity***
4.4.1	**Was RE used as a basis to design a replacement?** Yes. Reverse-engineering techniques were used to gather the dimensional and functional requirements of the original power supply and the modified design. A replacement power supply was designed based on these inputs.
4.4.2	**Does the RE item require a change to the FSAR?** No. The customer determined that no change was required to the FSAR.
4.4.3	**Is an in situ engineering special test/inspection required?** No. However, the customer planned to test one of the replacement units in a non-plant application (for example, a simulator) before installing them in the field.
4.4.4	**Are new failure modes introduced?** A possible failure mechanism of thermal shutdown was identified. However, the customer was able to determine that actual operating conditions would not result in thermal shutdown as discussed in Step 4.3.2.
4.4.5	**Are Operations-critical document (OCD) updates required?** No. The customer determined that no OCD updates were required.

Flowchart Step	Description
4.4.6	**Any changes to bounded technical requirements?** No. The customer determined that there are no changes to bounded technical requirements.
4.4.7	**Is a review of equipment qualification required?** Yes. New mild environment, seismic, and EMI/RFI qualification testing was performed. Therefore, a design engineering review was required (Step 4.7), and the new qualification reports were submitted to the customer for design engineering review and approval.
4.4.8	**Could differences impact calculations?** No. This power supply was designed specifically for this system, so there was no impact to the system design.
4.7	**Design engineering review** The customer's design engineering review concluded that the design for the replacement item should be controlled using the design equivalent change process.

11
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A
FORM FOR INITIATING APPLICATION OF REVERSE-ENGINEERING TECHNIQUES

There is no standard format for documenting the application of reverse-engineering techniques. It is acceptable for different organizations to document the process in different ways, and the format may vary depending on the type of organization.

The forms included in this appendix are intended to provide an example of a basic format for documenting the process. The forms do not include provisions for documenting all aspects of a reverse-engineering project. However, the forms do include important information that should be communicated about the equipment and applications for which reverse-engineering techniques are being applied.

A.1 Purpose

The form included in this appendix is intended for use when initiating a project that involves application of reverse-engineering techniques. The intent of the form is to capture and communicate information that must be considered during the reverse-engineering process.

Instructions for completing each section and field in the form are included in Section A.2 of this attachment as well as images of the form. A working Microsoft ® Word copy of the form is included as an attachment to the electronic version of this report. It can be accessed by clicking on the Attachments icon (paperclip) in the Adobe navigation panes, right-clicking on the document name, and selecting “Save Attachment” from the drop-down menu.

A.2 Instructions for Completing the Form

Section A, Contact Information

The information to enter in each of the fields of Section A is as follows:

- **Contact information**. Enter the names of the customer and supplier business and technical contacts and their contact information.

Section B, Item Identification

The information to enter in the data fields of Section B is as follows:

- **Inventory control number**. Provide the unique code used to identify the item in the inventory management system (for example, stock code, catalog identifier, material number, and stock-keeping unit).
- **Noun identifier.** Specify the name of the item, typically presented in a noun-adjective-additional-information format (for example, “stem, valve, stainless steel”).

- **Description.** Enter a description of the item.
- **Original manufacturer nam**e. Enter the name of the entity that originally manufactured the item if known.
- **Manufacturer model/part/catalog number(s)**. Provide a product identifier, such as the manufacturer's assigned identifier for an item. The part number (as referred to in this report) can also include identifiers such as model number, material type, grade, or catalog reference number.
- **Original supplier name**. Enter the name of the entity that originally supplied the item if it is different from the entity that originally manufactured the item.
- **Supplier model/part/catalog number(s)**. Provide a product identifier, such as the supplier's assigned identifier for an item if it is different from the manufacturer model/part/catalog number.

Section C, Item Information

The information to enter in the data fields of Section C of the form is as follows:

- **Production status**. Use the "Yes" or "No" checkbox to indicate whether the item is obsolete. In this context, *obsolete* means the item is no longer manufactured or is otherwise difficult to procure and qualify.
- **Equipment ID (tag) numbers or description of item usage**. Identify applicable equipment (for example, the tag number(s)) for which the item is intended. When the item is used in numerous applications, such as a commodity item, describe the intended end-use applications. For example, "This cap screw is used in accordance with piping specifications ABC and XYZ as a pressure-retaining bolting component in safety-related piping system flanged connections."
- **Parent component/host description**. Briefly describe the parent/host components/systems.
- **Functional safety class of item**. Identify the item as safety-related or non-safety-related.
- **Basis/source.** List the basis or source of the item safety classification. Typical sources might include previous safety classification evaluations; system descriptions; equipment lists; quality assurance level lists (Q-lists); critical structures, systems, and components (CSSC) lists; and so forth.
- **Identification of item function**. Provide information on the actual functions of the item within the system or component in which it is installed. Information should include functional requirements during normal operations as well as during and following a design basis accident. Items may have more than a single function. For example, a relay could have both a passive function (maintaining 1E circuit integrity) and an active function (closing to prevent damage to the 1E circuit). Both safety functional classifications would be listed.
- **Impact on function of host component/system**. Describe how the item affects the function of the host component and system.
- **Special requirements (Check all that apply)**. Identify special requirements such as environmental or seismic qualification.

Section D, Available Information

The information to include in the data fields of Section D of the form is as follows:

- **Availability of specimen(s)**. Indicate the availability of specimens to which reverse-engineering techniques can be applied.
- **Condition of specimen(s)**. Indicate the condition of specimen to which reverse-engineering techniques can be applied.
- **Availability of interfacing items**. Indicate the availability of interfacing items that could be used to enhance the application of reverse-engineering techniques.
- **Condition of interfacing items**. Indicate the condition of interfacing items that could be used to enhance the application of reverse-engineering techniques.
- **Comments related to specimen and interfacing items**. Include comments about the condition, availability, or types of interfacing items available.
- **Available drawings and documents**. Identify available drawings and documents such as old purchase orders, certification packages, design basis document excerpts, manuals, datasheets, specifications, and so forth.
- **Known item characteristics**. List known characteristics of the item.
- **Available operating experience**. Provide operating experience that can be made available such as plant maintenance history, incident information found on NRC's ADAMS website, and incident information reported to operating experience databases to which the customer is subscribed
- **Corrective action/Maintenance feedback/history** (that would suggest enhancements). Provide information from corrective action systems and feedback from Operations and Maintenance that might highlight problematic aspects of the item or suggest enhancements that might be appropriate for the item.
- **In situ conditions/environmental requirements**. Provide in situ conditions such as under-voltage, over-voltage, temperature and other environmental factors.
- **Seismic and environmental qualification requirements**. Provide applicable seismic and environmental qualification requirements including EMI/RFI.

Section E, Supplier Information

The information to include in each of the data fields of Section E of the form is as follows:

- **Reason for application of reverse-engineering techniques**. Select the appropriate reason. If the reason is "other," describe the reason.
- **Testing and examination anticipated**. Select the types of testing and examination that are anticipated.

Reverse-Engineering Project Initiation Form **EPRI Joint Utility Task Group**
Form RE1, Rev. 0

SECTION A CONTACT INFORMATION

CUSTOMER BUSINESS CONTACT, EMAIL, PHONE:	CUSTOMER TECHNICAL CONTACT, EMAIL, PHONE:
SUPPLIER BUSINESS CONTACT, EMAIL, PHONE:	**SUPPLIER TECHNICAL CONTACT, EMAIL, PHONE:**

SECTION B ITEM IDENTIFICATION

INVENTORY CONTROL NO:	
NOUN IDENTIFIER:	
DESCRIPTION:	
ORIGINAL MANUFACTURER NAME:	**MANUFACTURER MODEL / PART / CATALOG NUMBER(S)**
ORIGINAL SUPPLIER NAME (IF DIFFERENT):	**SUPPLIER MODEL / PART / CATALOG NUMBER(S)**

SECTION C ITEM INFORMATION

PRODUCTION STATUS:		
Is the item obsolete?	☒ Yes	☐ No
EQUIPMENT ID (TAG) NUMBERS OR DESCRIPTION OF ITEM USAGE:		
PARENT COMPONENT/HOST DESCRIPTION:		
FUNCTIONAL SAFETY CLASS OF ITEM:	**BASIS / SOURCE:**	
☒ Safety-Related ☐ Non-Safety Related		
DESCRIPTION OF ITEM FUNCTION		
IMPACT ON FUNCTION OF HOST COMPONENT / SYSTEM		
SPECIAL REQUIREMENTS (CHECK ALL THAT APPLY):		
☐ EQ ☐ CLASS 1E ☐ SEISMIC CLASS 1 ☐ OTHER: (see below)	☐ ASME SECTION III ☐ CONTAINMENT PRESSURE BOUNDARY ☐ SERVICE LEVEL 1 COATING	

Reverse-Engineering Project Initiation Form **EPRI Joint Utility Task Group**
Form RE1, Rev. 0

SECTION D AVAILABLE INFORMATION

AVAILABILITY OF SPECIMEN(S):	CONDITION OF SPECIMEN(S):		
☐ A single specimen is available	Is specimen new or used?	☐ New	☐ Used
☐ Multiple specimens are available	Is the specimen contaminated?	☐ Yes	☐ No
☐ No specimens are available	Can the specimen be destroyed?	☐ Yes	☐ No
AVAILABILITY OF INTERFACING ITEMS:	**CONDITION OF INTERFACING ITEMS:**		
☐ All interfacing items are available	Are items new or used?	☐ New	☐ Used
☐ Some interfacing items available	Are items contaminated?	☐ Yes	☐ No
☐ No interfacing items available	Can the items be destroyed?	☐ Yes	☐ No
COMMENTS RELATED TO SPECIMEN AND INTERFACING ITEMS:			
AVAILABLE DRAWINGS AND DOCUMENTS:			
KNOWN ITEM CHARACTERISTICS:			
AVAILABLE OPERATING EXPERIENCE:			
CORRECTIVE ACTION/MAINTENANCE FEEDBACK / HISTORY (THAT WOULD SUGGEST ENHANCEMENTS)			
IN SITU CONDITIONS/ENVIRONMENTAL REQUIREMENTS			
ENVIRONMENTAL AND SEISMIC QUALIFICATION REQUIREMENTS			

Reverse-Engineering Project Initiation Form **EPRI Joint Utility Task Group**
Form RE1, Rev. 0

SECTION E SUPPLIER INFORMATION

REASON FOR APPLICATION OF REVERSE-ENGINEERING TECHNIQUES:	
☐	Obtain information necessary to enable procurement from an alternate source
☐	Recover information to develop a design for a replacement item used for a specific application
☐	Recover information to develop a design for a replacement item that can be used as a generic replacement in many applications
☐	Recover characteristic information for use in commercial grade dedication
☐	Other (describe below)

TESTING AND EXAMINATION ANTICIPATED:			
	Type of Test / Examination	Type of Equipment	
☐	Chemistry		
☐	Hardness		
☐	Tensile		
☐	Yield		
☐	Plating type & thickness		
☐	Heat treatment		
☐	Dimensions		
☐	Circuit analysis		

B
FORM FOR TRACKING AND DOCUMENTING INFORMATION RECOVERED DURING APPLICATION OF REVERSE-ENGINEERING TECHNIQUES

B.1 Purpose

The form included in this appendix is intended for use from beginning to end of the process for the application of reverse-engineering techniques to document recovered information. The intent of the form is to capture important information in a summarized format that can assist with both recovering information and vetting a design developed through application of reverse-engineering techniques.

A record that documents information as is it is collected can be used to update and exchange information with everyone involved in the project. This creates an opportunity for the entire team to develop a more thorough understanding of the design function(s) of the item being reverse engineered. The licensee can consider new information in light of the item's end-use application, interfaces, and functions. This may reveal that a site visit by the supplier and a walkdown of the item being replaced is warranted.

The form and information exchange can also help identify any technical and quality procurement requirements on purchase documents that may eventually need to be updated. Finally, the use of the form can assist in developing a test plan for a prototype if needed, and upon completion the test plan should be approved by the licensee in accordance with site procedures.

The types of information to capture in each column is discussed in Section B.2 of this attachment. An image of the form is also included in this attachment. A working Microsoft ® Word copy of the form is included as an attachment to the electronic version of this report. It can be accessed by clicking on the Attachments icon (paperclip) in the Adobe navigation panes, right-clicking on the document name, and selecting "Save Attachment" from the drop-down menu.

B.2 Instructions for Completing the Form

Section A, Contact Information

The following key is provided to better understand the type of information entered into each column in the example form on page B-3.

1. **No. (Number) input number.** Enter the unique number assigned to each input.
2. **Reference number.** Add the title or identifying number of the input document or source of the requirement.

3. **Exact wording of requirement design input from technical specification/reference.** Record the specific wording of the design input/requirement in this column.
4. **Requirement category.** Enter the category of the input/requirement (for example, seismic, qualification, structural, electrical, etc.).
5. **Classification.** Record whether input is for safety-related, augmented quality, non-safety, 1E, seismic, EMI/RFI, environmental, and so forth, if applicable.
6. **Document name.** Record the specific document name, section, and page number where the input/requirement is found
7. **Notes.** Use this section to record notes regarding the input/requirement.
8. **Most restrictive (worst case) application.** If the input/requirement is listed in several locations, list the location that contains the most restrictive requirements (for example, environmental conditions, equipment qualification, and so forth).
9. **Verification.** Record when the design verification was completed and how the design was verified.
10. **Validation**. Record when the design validation was completed and how the design was validated.

One of the benefits of documenting the ongoing exchange of information is that it creates an opportunity to better understand the design function(s) of the item being reverse engineered. This may occur through examination of the item itself and through the sharing of end-use information typically known by the licensee. The use of the form is also beneficial because it may reveal that a site visit by the supplier and a walkdown of the item being replaced is warranted.

The form and information exchange can also help identify any technical and quality procurement requirements on purchase documents that may eventually need to be updated. Finally, the use of the form can assist in developing a test plan for a prototype if needed, and upon completion the test plan should be approved by the licensee in accordance with site procedures.

Reverse-Engineering Requirements Matrix	***EPRI Joint Utility Task Group*** ***Form RE2, Rev. 0***

Requirements Matrix

NO.	REFERENCE NUMBER	EXACT WORDING OF REQUIREMENT/DESIGN INPUT FROM TECHNICAL SPECIFICATION/REFERENCE	REQUIREMENT CATEGORY	CLASSIFICATION	SOURCE DOCUMENT NAME, SECTION, AND PAGE NUMBER	NOTES	MOST RESTRICTIVE (WORST CASE) APPLICATION	VERIFICATION	VALIDATION
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

COMMENTS

Approvals:

_____ _____

Preparer Date

_____ _____

Reviewer Date

_____ _____

Quality Assurance Date

C
EXAMPLE OF SUMMARY REPORT FORMAT

The following forms, which were developed and are used by Nucleonova, provide an example of a format that can be used to produce a report that summarizes a reverse-engineering project.

nucleonova

RETR-NN-133XXX

REVERSE ENGINEERING TECHNICAL REPORT

Project: 133XXX – Ref. Client: XXXXXXXXXXXX

Page 3 of 6

Rev. 0

Project: **Title of the project**

Client: **XXXXXX** | Request for Quotation: **XXXXXXX** | Order: **XXXXXXXXXXXX**

CONCLUSION

PART A: GENERAL INFORMATION

SECTION A.1: OBJECTIVE AND SCOPE

PART B: PROCESS JUSTIFICATION

1	Is the spare part obsolete?	☐ YES (see observations) ☐ NO → **To acquire**
2	Are there manufacturers of similar models?	☐ YES → **Evaluation of Equivalence** ☐ NO
3	Is there historical information that proves the need for a redesign of the component to avoid repetitive failures or to improve/update the manufacturing process?	☐ YES → **Re-Engineering** ☐ NO → **Reverse Engineering**

Observations:

PART C: IDENTIFICATION OF RELEVANT INFORMATION

SECTION C.1: IDENTIFICATION OF THE COMPONENT

SECTION C.1.1: INFORMATION OF THE COMPONENT

Client Reference	Description	Manufacturer	Manufacturer. Ref.	Other

A. Available documentation of the component		Available		
Origin	Description	Yes	No	Partial
☐ Manufacturer		☐	☐	☐
☐ Maintenance		☐	☐	☐
☐ Engineering		☐	☐	☐
☐ Purchase/Reception		☐	☐	☐
		☐	☐	☐
☐ Regulation		☐	☐	☐
☐ Other		☐	☐	☐

Remarks:

NA: Not Available

SECTION C.1.2: CLASSIFICATION OF THE COMPONENT

Safety-Related:	Nuclear Qualification:
Seismic Qualification:	Electrical Qualification:
Environmental Qualification:	Supply subject to GC:

nucleonova

RETR-NN-133XXX

REVERSE ENGINEERING TECHNICAL REPORT

Project: 133XXX – Ref. Client: XXXXXXXXXXXX

Page 4 of 6

Rev. 0

Project: **Title of the project**

Client: **XXXXXX** Request for Quotation: **XXXXXXX** Order: **XXXXXXXXXXXX**

PART C: IDENTIFICATION OF RELEVANT INFORMATION (Cont.)

SECTION C.1.3: AVAILABILITY OF THE ORIGINAL COMPONENT

		Yes	No	N/A
1	Is there a spare part of this reference?	☐	☐	☐
2	Is the available component new?	☐	☐	☐
3	Has the component been extracted from its technical location and has it been used?	☐	☐	☐
4	Is it possible to extract information from the available spare part?	☐	☐	☐
5	Does the part meet the qualification required for the component?	☐	☐	☐
6	Can the extracted information be used as an Acceptance Criterion?	☐	☐	☐

Remarks:

SECTION C.2: IDENTIFICATION OF THE FINAL APPLICATION, ENVIRONMENT AND FUNCTION OF THE COMPONENT

SECTION C.2.1: FINAL APPLICATION AND ENVIRONMENT OF THE COMPONENT

Identification of the Target Set / Equipment	Description	Original Manufacturer	Manufacturer. Ref.

SECTION C.2.1.1 Available documentation of the final application and environment		Available		
Origin	Description	Yes	No	Partial
☐ Manufacturer		☐	☐	☐
☐ Maintenance		☐	☐	☐
☐ Engineering		☐	☐	☐
☐ Purchase/Reception		☐	☐	☐
☐ Regulation		☐	☐	☐
☐ Other		☐	☐	☐

Remarks: **NA: Not Available**

SECTION C.2.1.2 Characteristics / Environmental conditions

Operating Conditions		Environmental Conditions of the Room	
Fluid		Room	
Temperature (°C)		Temperature (°C)	
Humidity (RH %)		Humidity (RH %)	
Relative Pressure (mbar)		Relative Pressure (mbar)	
Radiation		Radiation	
Physical Characteristics of the Environment			
Connections and interactions with the component			

Remarks:

PART C: IDENTIFICATION OF RELEVANT INFORMATION (Cont.)

SECCTION C.2.2: FUNCTION OF THE COMPONENT

A. Function of the component	SR	NSR	Active Comp.	Passive Comp.	Electrical Integrity	Structural Integrity
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐

Remarks:

Note: By selecting the functional modes on the left side, the functional modes on the right are included.
ACTIVE >> PASSIVE >> ELECTRICAL INTEGRITY >> STRUCTURAL INTEGRITY
SR: Safety Related; **NSR**: Non-Safety Related

Example of Summary Report Format

nucleonova

RETR-NN-133XXX

REVERSE ENGINEERING TECHNICAL REPORT

Project: 133XXX – Client Ref.: XXXXXXXXXXXX

Rev. 0

Project: **Title of the project**

Client: **XXXXXX** | Request for Quotation: **XXXXXXX** | Order: **XXXXXXXXXXXX**

PART D: DEFINITION OF DESIGN CHARACTERISTICS (CD)

SECTION D.1 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Functions	Failure Mode	Effect	Cause	Control / Design Characteristic
				-
				-
				-
				-

Remarks:

SECTION D.2 IDENTITY/ EQUIVALENCE EVALUATION

Design Characteristic (DC)	Initial Start Data	Reference	Action to be taken	Final document / Evidence action taken	Definitive value in the Technical specification	Results
A.						
B.						
C.						

Remarks and List of References:

Reference	Document
[1]	
[2]	
[3]	

According to the results obtained from the analysis performed on the component, there is a reasonable guarantee to consider the spare parts:

☐ Identical to the original ("Like for like").

☐ Alternative to the original ("Equivalent Replacement", suitable for the Technical Location of the "original spare").

NA: Not Available

PART E: JUSTIFICATION OF VALUES FOR DESIGN CHARACTERISTCS AND DECISION MAKING

SECTION E.1: INDIVIDUAL JUSTIFICATION FOR THE DESIGN CHARACTERISTCS

A.	
B.	
C.	

Remarks:

PART F: VALIDATION IN SITU ☐ Pending to perform

The results obtained for In Situ Validation are shown below, after carrying out the functional tests in the Technical Location where the component will perform its Safety-related function, or equivalent.

DESCRIPTION	YES	NO	N/A	Result	Record
SECTION F.1. RECEPTION AND IDENTIFICATION					
Has it been verified that the first manufactured unit complies with the design characteristics defined in section D. 2 of this document?					
Does the component to be tested correspond to the prototype / material sent for that purpose according to the order?					
Has a visual inspection of the component been made by checking the general configuration of the component and the absence of damage, shock and/or imperfections?					
SECTION F.2. FUNCTIONAL TESTING					
Is it verified that the test will be carried out according to the applicable Procedure/Range?					
Do the personnel who execute the tests have the necessary qualifications?					
Are the used equipment/tools adequate and verified?					
Has the correct functioning of the component been checked?					

Remarks:

PART G: INSTALLATION AND STORAGE RECOMMENDATIONS

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