PART 4 CONTENTS

Risk-Based Inspection Methodology
Part 4—Inspection Planning Methodology

4 SCOPE

The calculation of risk outlined in API 581 involves the determination of a probability of failure (POF) combined with the consequence of failure (COF). Failure is defined as a loss of containment from the pressure boundary. Risk increases as damage accumulates during in-service operation as the risk tolerance or risk target is approached and an inspection is recommended of sufficient effectiveness to better quantify the damage state of the component. The inspection action itself does not reduce the risk; however, it does reduce uncertainty and therefore allows more accurate quantification of the damage present in the component.

4.1 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 580*, Risk-Based Inspection*, American Petroleum Institute, Washington, DC.

API Recommended Practice 581, *Risk-Based Inspection Methodology, Part 1—Inspection Planning Methodology*

API Recommended Practice 581, *Risk-Based Inspection Methodology, Part 2—Probability of Failure Methodology*

API Recommended Practice 581, *Risk-Based Inspection Methodology, Part 3—Consequence of Failure Methodology*

API Recommended Practice 581, *Risk-Based Inspection Methodology, Part 5—Risk-Based Inspection Methodology for Special Equipment*

4.2 Inspection Planning Based on Risk

4.2.1 Overview

Inspection planning based on risk assumes that at some point in time, the risk as defined by Part 1, Equation (1.7) and Part 1, Equation (1.8) will reach or exceed a user-defined area or financial risk target. When or before the user-defined risk target is reached, an inspection of the equipment is recommended based on the component damage mechanisms with the highest DFs. The user may set additional targets to initiate an inspection, such as POF, DF, COF, inspection interval or thickness. In addition, inspection may be conducted solely to gather information to reduce uncertainty in the component condition or based on an engineering evaluation of the fitness for continued service rather than the RBI results.

Although inspection of a component does not reduce the inherent risk, inspection provides improved knowledge of the current state of the component and therefore reduces uncertainty. The probability that loss of containment will occur is directly related to the known condition of the component based on information from inspection and the ability to accurately quantify damage.

Reduction in uncertainty in the damage state of a component is a function of the effectiveness of the inspection to identify the type and quantify the extent of damage. Inspection plans are designed to detect and quantify the specific types of damage expected such as local or general thinning, cracking, and other types of damage. An inspection strategy that is appropriate for general thinning may not be effective in detecting and quantifying damage due to local thinning or cracking. Therefore, the inspection effectiveness is a function of the inspection method and extent of coverage used for detecting the type of damage expected.

Risk is a function of time, as shown in Part 1, Equation (1.7), Part 1, Equation (1.8), and Part 1, Equation (1.9), as well as a function of the knowledge of the current state of the component determined from past inspections. When inspection effectiveness is introduced into risk Part 1, Equation (1.7), Part 1, Equation (1.8), Part 1, Equation (1.9), the equations can be rewritten as Equation (4.1) and Equation (4.2), Equation (4.3):

$$R(t,I_E) = P_f(t,I_E)\cdot CA_f^{area} \quad \text{for area-based risk} \tag{4.1}$$

$$R(t,I_E) = P_f(t,I_E)\cdot CA_f^{fin} \quad \text{for financial-based risk} \tag{4.2}$$

$$R(t,I_E) = P_f(t,I_E)\cdot CA_f^{inj} \quad \text{for safety-based risk} \tag{4.3}$$

4.2.2 Targets

A target is defined as the maximum level acceptable for continued operation without requiring a mitigating action. Once the target has been met or exceeded, an activity such as inspection is triggered. Several targets can be defined in an RBI program to initiate and define risk mitigation activities, as follows.

a) Risk Target—A level of acceptable risk that triggers the inspection planning process. The risk target may be expressed in area, C_f^{area}, (ft²/year), financial, C_f^{fin}, ($/year) or safety, C_f^{inj}, (injuries/year) terms, based on the owner–~~user~~operator preference. One or more risk targets may be set manage the mechanical integrity risk of components within defined acceptable limits.

b) POF Target—A frequency of failure or leak (#/year) that is considered unacceptable and triggers the inspection planning process. A POF target may be set drive inspection for components with a very low COF and Risk but where frequent, nuisance leaks are undesirable.

c) DF Target—A damage state that reflects an unacceptable failure frequency factor greater than the generic and triggers the inspection planning process. Similar to a POF Target, a maximum DF target may be set to drive inspection for components with very low COF and Risk but where frequent, nuisance leaks are undesirable. Minimum DF targets may be set by damage mechanism type to prevent inspection recommendations for components with very low DF but high COF and Risk where inspection will not effectively reduce Risk.

d) Minimum DF Target—A minimum DF where inspection will not effectively reduce risk. In this case, risk is consequence driven and other mitigation methods are recommended.

e) COF Target—A level of unacceptable consequence in terms of consequence area (C_f^{area}), financial consequence (C_f^{fin}) or safety consequence (C_f^{inj}) based on owner–~~user~~operator preference. Because risk driven by COF is not reduced by inspection activities, risk mitigation activities to reduce release inventory or ignition are required.

f) Thickness Target—A specific thickness, often the minimum required thickness, t_{min}, considered unacceptable, triggering the inspection planning process. A minimum Thickness target may be set to drive inspection for components at a predetermined thickness (for example ½ wall or 0.100 in), independent of DF, POF or Risk.

g) Maximum Inspection Interval Target—A specific inspection frequency considered unacceptable, triggering the inspection planning process. A maximum inspection interval may be set by the owner–~~user~~operator's corporate standards or may be set based on a jurisdictional requirement. A maximum inspection interval may be set to require an inspection be performed at a specified maximum interval, independent of DF, POF or Risk.

It is important to note that defining targets is the responsibility of the owner–~~user~~operator and that specific target criteria is not provided within this document. The above targets should be developed based on owner–~~user~~operator internal guidelines and overall risk tolerance. Owner–~~user~~operators often have corporate risk criteria defining acceptable and prudent levels of safety, environmental, and financial risks. These owner–~~user~~operator criteria should be used when making RBI decisions since acceptable risk levels and risk management decision-making will vary among companies.

4.2.3 Inspection Effectiveness—The Value of Inspection

An estimate of the POF for a component depends on how well the independent variables of the limit state are known [10] and understood. Using examples and guidance for inspection effectiveness provided in Part 2, Annex 2.F, an inspection plan is developed, as risk results require. The inspection strategy is implemented to obtain the necessary information to decrease uncertainty about the actual damage state of the equipment by confirming the presence of damage, obtaining a more accurate estimate of the damage rate, and evaluating the extent of damage.

An inspection plan is the combination of NDE methods (i.e. visual, ultrasonic, radiographic, etc.), frequency of inspection, and the location and coverage of an inspection to find a specific type of damage. Inspection plans vary in their overall effectiveness for locating and sizing specific damage and understanding the extent of the damage.

Inspection effectiveness is introduced into the POF calculation using Bayesian Analysis, which updates the POF when additional data are gathered through inspection. The extent of reduction in the POF depends on the effectiveness of the inspection to detect and quantify a specific damage type of damage mechanism. Therefore, higher inspection effectiveness levels will reduce the uncertainty of the damage state of the component and reduce the POF. The POF and associated risk may be calculated at a current and/or future time period using Equation (4.1) or Equation (4.2).

Examples of the levels of inspection effectiveness categories for various damage mechanisms and the associated generic inspection plan (i.e. NDE techniques and coverage) for each damage mechanism are provided in Part 2, Annex 2.F. These tables provide examples of the levels of generic inspection plans for a specific damage mechanism. The tables are provided as a matter of example only, and it is the responsibility of the owner–~~user~~operator to create, adopt, and document their own specific levels of inspection effectiveness tables.

4.2.4 Calculation of Inspection Plan

The following procedure is used to determine the inspection required to achieve risk target prior to the Plan Date.

NOTE: this procedure applies to pressure vessels, piping, and Storage Tanks. The inspection planning process for heat exchanger bundles and PRDs are provided in Part 5 Section 4 and 5, respectively.

a) STEP 1—Assign dates to define Plan Period:

   1) Define the RBI Date (normally set to current date)

   2) Define Plan Date (normally the RBI Date + 10 years or 2 turnaround periods)

   3) Cracking Inspection Date (normally set to the mid-point between RBI Date and Plan Date or next turnaround)

b) STEP 2—Assign one or more targets as criteria for risk calculation and inspection recommendations (see Part 1, Section 2.3.2). If more than one target is used, indicate the priority of target analysis.

   1) Risk Target

1) Area Risk in ft²/year, $R(t)_{area-target}$

2) Financial Risk in $/year, $R(t)_{fin-target}$

3) Safety Risk in injuries/year, $R(t)_{inj-target}$

2) POF Target, $P_f(t)_{target}$

3) DF Target

1) Maximum DF Target, $D_{f-total,Max}$

2) Minimum DF Target

- D_{f-min}^{thin}
- D_{f-min}^{SCC}
- D_{f-min}^{extd}

4) Thickness Target, t_{target}

5) Maximum Inspection Interval, $Intvl_{target}$

c) STEP 3—Determine age_{tk} for each active damage mechanism and t_{rdi} for thinning and/or t_{rde} external for external damage mechanisms (see Part 2 for DF calculations Section 4 through Section 18).

d) STEP 4—Calculate age_{tk} at the $RBI\ Date$ and at 0.5 year intervals from the $RBI\ Date$ through the $Plan\ Date$ starting at age_{tk} from STEP 3.

e) STEP 5—Using the calculation steps in Part 2, calculate the DF for each active damage mechanism at 0.5 year intervals from the $RBI\ Date$ through the $Plan\ Date$.

f) STEP 6—Using the calculation steps in Part 2, calculate t_{rdi} and/or t_{rde} at 0.5 year intervals from the $RBI\ Date$ through the $Plan\ Date$.

g) STEP 7—Using the calculation steps in Part 2, Section 3.4.2, calculate $D_{f-total}$ at 0.5 year intervals from the $RBI\ Date$ through the $Plan\ Date$ using damage factors calculated in STEP 5. Set $D_f(t)_{f-total}^{woplan} = D_f(t)_{f-total} @ Plan\ Date$.

h) STEP 8—Using the equations in Part 2, Section 3.0, calculate $P_f(t)$ at 0.5 year intervals from the $RBI\ Date$ to the $Plan\ Date$ using $D_{f-total}$ calculated in Step 7 and gff_{total} from Table 3.1. Set $P_f(t)^{woplan} = P_f(t)\ @ Plan\ Date$.

i) STEP 9—Using the equations in Part 1, Section 4.3, calculate the area risk over time, $R(t)_{area}$ the financial risk, $R(t)_{fin}$, and safety risk, $R(t)_{inj}$ at 0.5 year intervals from the $RBI\ Date$ to the $Plan\ Date$ using $P_f(t)$ calculated in STEP 8, C_f (Part 3, Section 4 or Section 5) and C_f^{fin} (Part 3, Section 4.12). Set $R_f(t)_{safety}^{woplan} = R_f(t)@Plan\ Date$ and $R_f(t)_{fin}^{woplan} = R_f(t)@Plan\ Date$.

j) STEP 10—Based on the criteria selected in STEP 2, use the following logic to determine if inspection is required:

1) If $R_f(t)_{area}^{woplan} \le R(t)_{area-target}$, no inspection is required based on risk. Go to next target criteria. If $R_f(t)_{area}^{woplan} > R(t)_{area-target}$, inspection is required based on safety risk.

   a) Calculate the $Target\ Date$ based on the date the risk target is reached in STEP 9. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $R(t)_{area-target}$ is reached in STEP 9.

2) If $R_f(t)_{fin}^{woplan} \le R(t)_{fin-target}$, no inspection is required based on risk. Go to next target criteria. If $R_f(t)_{fin}^{woplan} > R(t)_{fin-target}$, inspection is required based on financial risk.

   a) Calculate the $Target\ Date$ based on the date the risk target is reached in STEP 9. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $R(t)_{fin-target}$ is reached in STEP 9.

3) If $R_f(t)_{inj}^{woplan} \le R(t)_{inj-target}$, no inspection is required based on risk. Go to next target criteria. If $R_f(t)_{inj}^{woplan} > R(t)_{inj-target}$, inspection is required based on injury risk.

   a) Calculate the $Target\ Date$ based on the date the risk target is reached in STEP 9. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $R(t)_{inj-target}$ is reached in STEP 9.

4) If $P_f(t)^{woplan} \le P(t)_{target}$, no inspection is required based on risk. Go to next target criteria. If $P_f(t)^{woplan} > P(t)_{target}$, inspection is required based on POF.

   a) Calculate the $Target\ Date$ based on the date that $P_f(t)_{target}$ is reached in STEP 8. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $P_f(t)_{target}$ is reached in STEP 8.

5) If $D_f(t)_{f-total}^{woplan} \le D_{f-total,Max}$, no inspection is required based on risk. Go to next target criteria. If $D_f(t)_{f-total}^{woplan} > D_{f-total,Max}$, inspection is required based on DF.

1) Calculate the $Target\ Date$ based on the date that $D_{f-total,Max}$ is reached in STEP 7. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $D_{f-total,Max}$ is reached in STEP 7.

6) If $t_{rdi}\ @\ Plan\ Date > t_{target}$, no inspection during plan period is required. Go to next target criteria. If $t_{rdi} \le t_{target}$, inspection is required based on thickness.

a) Calculate the $Target\ Date$ based on the date that t_{rdi} is reached in STEP 6. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where t_{target} is reached in STEP 6.

b) Calculate the date for inspection based on the remaining life fraction from the $Target\ Date$.

7) If $age_{tk}\ @ Plan\ Date \le Intvl_{target}$, no inspection during plan period is required. Go to next target criteria. If $age_{tk}\ @ Plan\ Date > Intvl_{target}$, a user defined inspection is required based on interval and go to STEP 12.

1) Calculate the $Target\ Date$ based on the date that $Intvl_{target}$ is reached in STEP 4. The $Target\ Date$ is calculated based on interpolating between 0.5 years points where $Intvl_{target}$ is reached in STEP 4.

8) If the component passes all of the applicable above criteria, set:

a) $R_f(t)_{area,plan} = R_f(t)_{area}^{woplan}$

b) $R_f(t)_{fin,plan} = R_f(t)_{fin}^{woplan}$

c) $R(t)_{inj-target} = R_f(t)_{inj}^{woplan}$

d) $P_f(t)_{plan} = P_f(t)^{woplan}$

e) $D_{f-total}^{plan} = D_{f-total}^{woplan}$

Go to STEP 14.

k) STEP 11— Calculate inspection requirements during plan period:

1) If $D_{f-gov}^{thin} \le D_{f-min}^{thin}$, $D_{f-gov}^{scc} \le D_{f-min}^{SCC}$, and $D_{f-gov}^{extd} \le D_{f-min}^{extd}$, risk is consequence driven and inspection will not effectively mitigate risk. Another mitigation method is recommended, go to Step 13.

2) Select the highest DF for each active damage mechanism type from STEP 5 and calculate DF, D_{f-gov}, $P(t)^{plan}$, $R_f(t)_{area,plan}$, $R_f(t)_{fin,plan}$, and $R(t)_{inj,plan}$ assuming a C level inspection will be conducted at the $Target\ Date$. If the damage mechanism is an SCC mechanism, use age_{tk} calculated using the $Cracking\ Inspection\ Date$ from STEP 1.

a) If $D_{f-gov}^{thin} \le D_{f-min}^{thin}$, $D_{f-gov}^{scc} \le D_{f-min}^{SCC}$, and $D_{f-gov}^{extd} \le D_{f-min}^{extd}$, no further inspection mitigation is required, go to STEP 13.

b) If $R_f(t)_{area}^{plan} \le R(t)_{area-target}$, $R_f(t)_{fin}^{plan} \le R(t)_{fin-target}$, $R_f(t)_{inj}^{plan} \le R(t)_{inj-target}$, and $D_{f-total} < D_{f-min}$, the inspection is sufficient to satisfy the target and go to STEP 13.

3) Select the D_{f-gov} of the active damage mechanism type from the previous calculation and repeat the calculation with a C level inspection or next highest inspection category. Calculate $D_{f-total}$, $P(t)^{plan}$, $R_f(t)_{area,plan}$, $R_f(t)_{fin,plan}$, $R_f(t)_{inj,plan}$ assuming the inspection will performed at the $Target\ Date$. If the damage mechanism is an SCC mechanism, use age_{tk} calculated using the $Cracking\ Inspection\ Date$ from STEP 1.

a) If $D_f^{thin} \le D_{f-min}^{thin}$, $D_f^{SCC} \le D_{f-min}^{SCC}$, and $D_f^{extd} \le D_{f-min}^{extd}$, no further inspection mitigation is required, go to STEP 12.

b) If $R_f(t)_{area}^{plan} \le R(t)_{area-target}$, $R_f(t)_{fin}^{plan} \le R(t)_{fin-target}$, $R_f(t)_{inj}^{plan} \le R(t)_{inj-target}$, and $D_{f-total} < D_{f-min}$, the inspection is sufficient to satisfy the target and go to STEP 13.

4) Repeat the calculation procedure above for the D_{f-gov} of the active damage mechanism type from the previous step and calculate $R_f(t)_{area}^{plan} \le R(t)_{area-target}$, $R_f(t)_{fin}^{plan} \le R(t)_{fin-target}$, $R_f(t)_{inj}^{plan} \le R(t)_{inj-target}$, and $D_{f-total} < D_{f-min}$ until the inspection is sufficient to satisfy the target or an A level inspection has been reached for each active mechanism.

5) Apply the highest level of inspection identified for the D_{f-gov} of all active damage mechanisms types.

l) STEP 12—Calculate D_{f-gov}, $P(t)^{plan}$, $R_f(t)_{area,plan}$, $R_f(t)_{fin,plan}$, and $R_f(t)_{inj,plan}$ for all active damage mechanism types after applying the inspection defined in STEP 11.

m) STEP 13—Calculate, $D_{f-total}^{plan}$, $P(t)^{plan}$, $R(t)_{area}^{plan}$, $R(t)_{fin}^{plan}$, and $R(t)_{inj}^{plan}$ at the $Plan\ Date$ using the inspection recommended in STEP 11, performed at the $Target\ Date$.

n) STEP 14—Calculate the final $Target\ Date$:

1) If no inspection is required, set $Target\ Date = Plan\ Date$.

2) If inspection is required, use the recommended inspection plan (A, B or C inspection effectiveness) and $Target\ Date$ defined in STEP 11 for the applicable criteria using the minimum date for the applicable criteria in STEPs 4, and 6 through 10.

4.2.5 Inspection Planning

An inspection plan date covers a defined plan period and includes one or more future maintenance turnarounds. Within this plan period, three cases are possible based on predicted risk and the risk target.

a) Case 1—Risk Target Is Exceeded During the Plan Period—As shown in Figure 4.1, the inspection plan will be based on the inspection effectiveness required to reduce the risk and maintain it below the risk target through the plan period.

b) Case 2—Risk Exceeds the Risk Target at the Time the RBI Date—As shown in Figure 4.2, the risk at the start time of the RBI analysis, or RBI date, exceeds the risk target. An inspection is recommended as soon as practical. The plan should be sufficient to reduce the risk so that the risk after inspection remains below the risk target at the plan date. In addition, elevated risk levels should be communicated with management and a risk mitigation plan should be developed and implemented within an acceptable time period.

c) Case 3—Risk at the Plan Date Does Not Exceed the Risk Target—As shown in Figure 4.3, the risk at the plan date does not exceed the risk target and therefore no inspection is required during the plan period. In this case, the inspection due date for inspection scheduling purposes may be set to the plan date so that reanalysis of risk will be performed by the end of the plan period.

The concept of how the different inspection techniques with different effectiveness levels can reduce risk is shown in Figure 4.1. In the example shown, a minimum of a *B Level* inspection was recommended at the target date. This inspection level was sufficient since the risk predicted after the inspection was performed was determined to be below the risk target at the plan date.

NOTE: Figure 4.1, a *C Level* inspection at the target date would not have been sufficient to satisfy the risk target criteria.

4.3 Nomenclature

age_{tk} is the time since the last A or B effective lining inspection

C_f is the COF, m^2 (ft^2), $ or injuries

C_f^{area} is the ~~safety~~ consequence impact area, m^2 (ft^2)

C_f^{fin} is the financial consequence, $

C_f^{inj} is the safety consequence, injuries

$D_{f-total}$ is total DF for POF calculation

$D_{f-total,Max}$ is maximum total DF target for inspection planning

D_{f-gov}^{extd} is the governing DF external damage

D_{f-min}^{extd} is the governing external DF minimum target for inspection planning

D_{f-gov}^{scc} is the governing DF for SCC

D_{f-min}^{SCC} is the governing DF SCC minimum target for inspection planning

D_{f-gov}^{thin} is the governing DF for thinning

D_{f-min}^{thin} is the governing DF thinning minimum target for inspection planning

$D_f(t)$ is the DF as a function of time, equal to $D_{f\text{-}total}$ evaluated at a specific time

$D_{f-total}^{plan}$ is the DF at the plan date with inspection

$D_f(t)_{f-total}^{woplan}$ is the DF at the plan date without inspection

gff_{total} is the total GFF, failures/year

$Intvl_{target}$ is the interval target for inspection planning

Plan Date is the date set by the owner–~~user~~operator that defines the end of plan period

$P_f(t)$ is the POF as a function of time, failures/year

$P_f(t, I_E)$ is the POF as a function of time and inspection effectiveness, failures/year

$P_f(t)_{target}$ is the POF target for inspection planning, failures/year

$P_f(t)_{plan}$ is the POF at the plan date before the planned inspection, failures/year

$P_f(t)^{woplan}$ is the POF at the plan date after the planned inspection, failures/year

RBI Date is date set by the owner–~~user~~operator that defines the start of a plan period

$R(t)$ is the risk as a function of time, m^2/year (ft^2/year), $/year, or injuries/year

$R(t, I_E)$ is the risk as a function of time and inspection effectiveness, m^2/year (ft^2/year), $/year, injuries/year

$R(t)_{area}$ is the area risk as a function of time, m^2/year (ft^2/year)

$R(t)_{area-target}$ is the level of acceptable safety risk that triggers the inspection planning process, m^2/year (ft^2/year)

$R_f(t)_{area,plan}$ is the safety risk at the plan date before the planned inspection, m^2/year (ft^2/year)

$R_f(t)^{woplan}_{area}$ is the safety risk at the plan date after the planned inspection, m^2/year (ft^2/year)

$R(t)_{inj}$ is the ~~injury~~safety risk as a function of time, injuries/year

Commented [RS1]: Lynne, should this be "safety" instead of "injury" like the others?

$R(t)_{inj-target}$ is the level of acceptable safety risk that triggers the inspection planning process, injuries/year

$R_f(t)_{inj,plan}$ is the safety risk at the plan date before the planned inspection, injuries/year

$R_f(t)^{woplan}_{inj}$ is the safety risk at the plan date after the planned inspection, injuries/year

$R(t)_{fin}$ is the financial risk as a function of time, $/year

$R(t)_{fin-target}$ is the level of acceptable financial risk that triggers the inspection planning process, $/year

$R_f(t)_{fin,plan}$ is the financial risk at the plan date before the planned inspection, $/year

$R_f(t)^{woplan}_{fin}$ is the financial risk at the plan date after the planned inspection, $/year

Target Date is the date where the risk target is expected to be reached and is the date at or before the recommended inspection should be performed

t_{rdi} the furnished thickness, t, or measured thickness reading from previous inspection, only if there is a high level of confidence in its accuracy, with respect to wall loss associated with internal corrosion

t_{rde} is the measured thickness reading from previous inspection with respect to wall loss associated with external corrosion

t_{target} is the thickness target for inspection planning

4.4 Tables

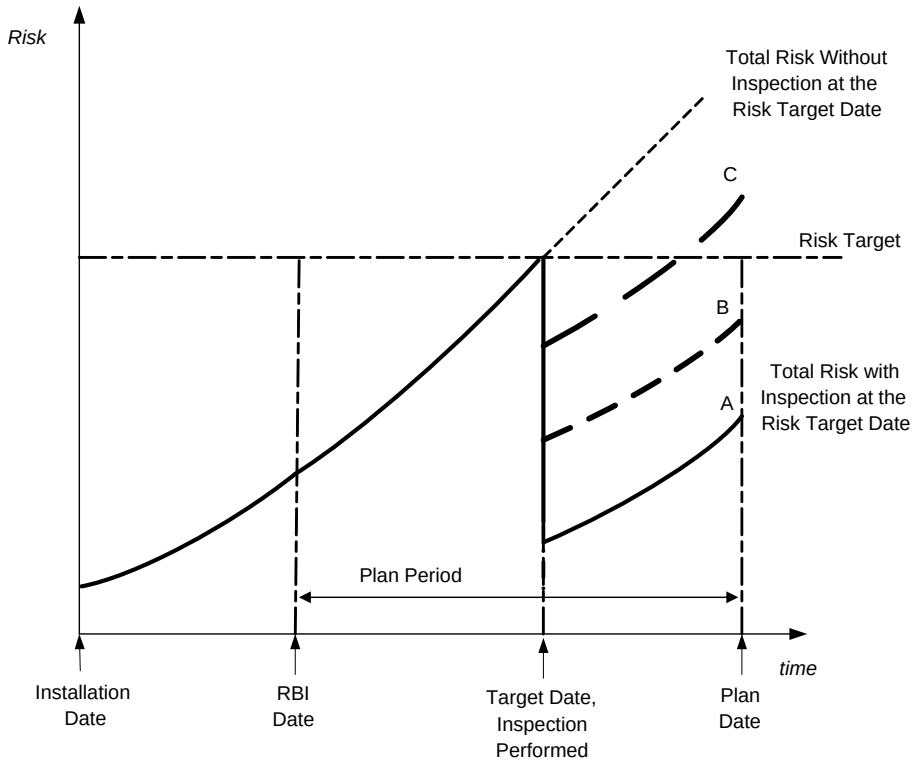

Figure 4.1—Case 1: Inspection Planning when the Risk Target Is Exceeded During the Plan Period

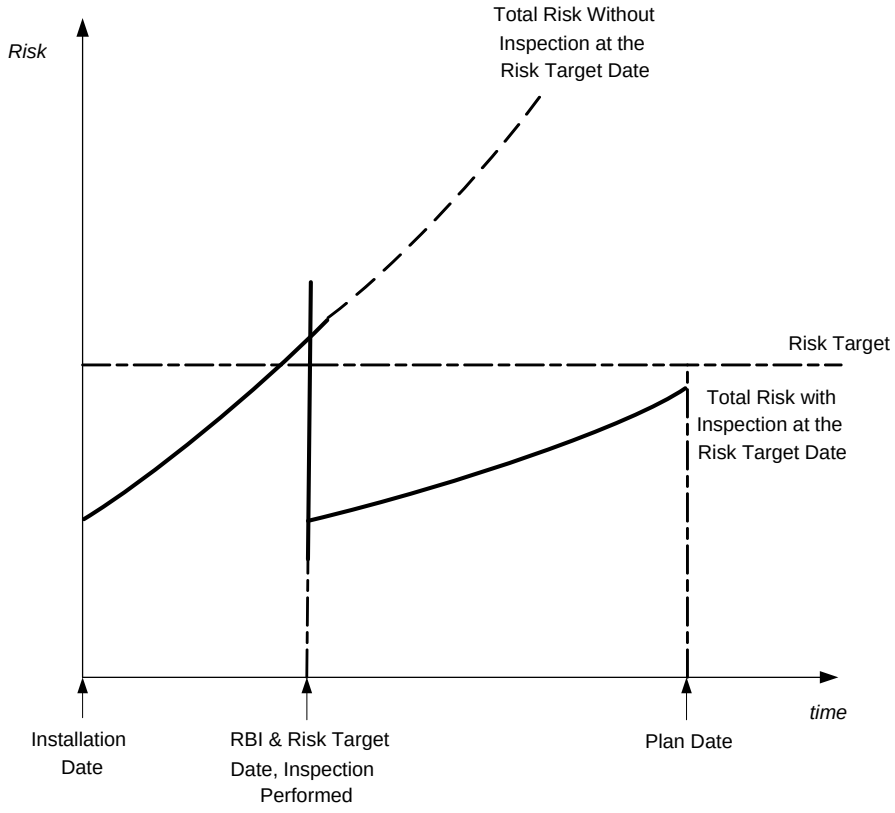

Figure 4.2—Case 2: Inspection Planning when the Risk Target Has Been Exceeded at or Prior to the RBI Date

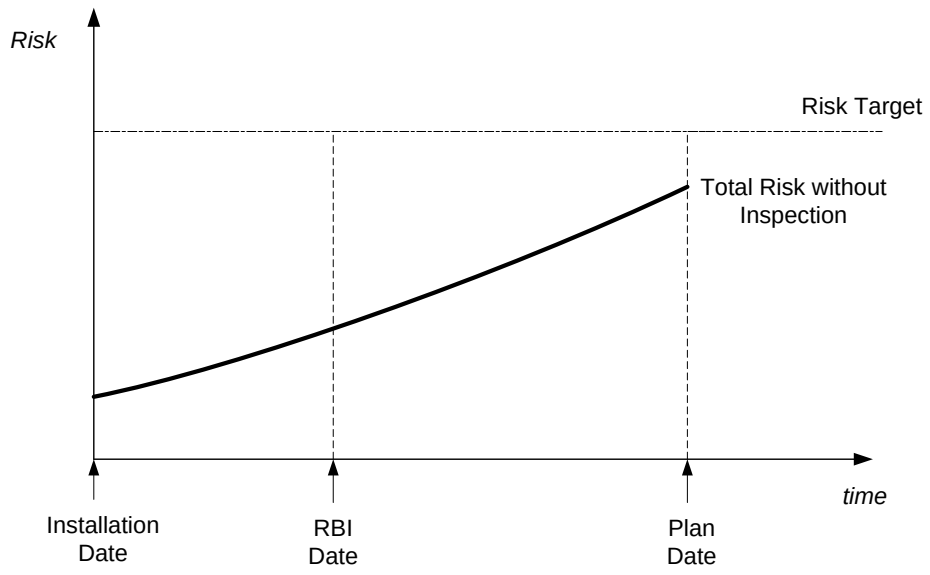

Figure 4.3—Case 3: Inspection Planning when Risk Target Is Not Exceeded During the Plan Period