VAŽNOST PRIMENE ANALIZE RIZIKA KOD OPREME POD PRITISKOM KOJA SE ISPITUJE PO POSEBNOM PROGRAMU

IMPORTANCE OF APPLYING RISK ANALYSIS TO PRESSURE EQUIPMENT TESTED BY A SPECIAL PROGRAM

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Oprema pod pritiskom se prema PED 2014/68 i Pravilniku o tehničkim zahtevima za projektovanje, izradu i ocenjivanje usaglašenosti opreme pod pritiskom deli na opremu visokog i niskog nivoa opasnost, u zavisnosti od vrste opreme, stanja i grupe fluida i proizvoda zapremine i pritiska, odnosno akumulirane energije. Ova oprema se ispituje prema Pravilniku o pregledu opreme pod pritiskom tokom veka upotrebe. Međutim, postoji određeni broj opreme pod pritiskom koji ne može da se ispituje po redovnom programu, najčešće zbog svoje konstrukcije, ili radnog fluida. Ova oprema se ispituje po posebnom programu koji se pravi za svaku opremu posebno. U sklopu ovog programa potrebno je uraditi i analizu rizika. U ovom radu će biti pojašnjena važnost primene analize rizika i biće prikazana njena primena na određene sklopove opreme.

***Ključne reči:** oprema pod pritiskom, PED, analiza rizika*

According to PED 2014/68 and the Regulation on technical requirements for design, manufacture and conformity assessment of pressure equipment, pressure equipment is divided into high- and low-level risk level equipment, depending on the type of equipment, condition and group of fluids and products of volume and pressure, i.e. accumulated energy. This equipment is tested according to the Regulation on the inspection of pressure equipment during its service life. However, there are a number of pressure equipment that cannot be tested according to a regular program, most often due to their construction, or working fluid. This equipment is tested according to a special program that is made for each equipment particular. As part of this program, it is necessary to do a risk analysis. This paper will explain the importance of applying risk analysis and will show its application to certain sets of equipment.

***Key words**: pressure equipment, PED, risk analysis*

1 Introduction

The Ordinance on technical requirements for the design, manufacture and conformity assessment of pressure equipment (1) and PED 2014/68 (2) define the conditions and obligations under which the pressure equipment is designed, manufactured and assessed, while the Ordinance on inspections of pressure equipment during life time (3) defines requirements for the safety of pressure equipment during the service life, regular and extraordinary inspections at the place of use, procedures and deadlines for inspection and testing of pressure equipment in use and the requirements to be met by the inspection bodies in order to be designated for the classification of pressure equipment and/or inspections and tests of pressure equipment, then the obligations of the user and the inspection body on inspections of pressure equipment in operation. Ordinance (3) provides for a pre-commissioning inspection, a first inspection, a regular periodic inspection and an extraordinary inspection. There are three types of regular periodic inspection: external, internal and pressure testing. In special cases, the internal examination may be replaced by an equivalent method, as well as a pressure test. However,

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depending on the technical construction and / or operating conditions, there are exceptions in which the equipment needs to be tested according to a special program.

Croatian Ordinance (4) contains an appendix which lists the pressure equipment that requires treatment according to a special program. Our Ordinance (3) maintained that the Special Periodic Inspection Program is defined in the technical documentation of the pressure equipment manufacturer. This documentation contains the scope and deadlines of the examination. However, there are exceptions when the manufacturer does not provide a special program, and the equipment is subject to a special inspection program because due to the specific working conditions and technical complexity cannot be inspected according to the regular program of periodic inspections. The practice solves these problems, with the approval of Ministry of mining and energy Republic of Serbia, in a way that the user makes a special program, and the body for inspection and testing of pressure equipment approves and certifies it.

The ordinance does not define in detail what a special program for periodic inspection of pressure equipment should contain. This paper will present the role of risk analysis in compiling a special program of periodic inspections of pressure equipment, will provide an overview of standards related to risk analysis, discussed examples of pressure equipment that can not be tested by regular periodic program and analyzed and discussed example of membrane battery for which a special program was made.

2 Risk analysis and pressure equipment tested according to a special program

Risk analysis is the process of assessing the probability that negative events will occur within a system, and in our case a pressure vessel. The purpose of risk analysis and assessment is to make and implement measures and decisions in order to treat certain risks and eliminate them, based on the information and evidence obtained.

Risk-based inspection (RBI) is a methodology and procedure of analysis which, unlike condition-based inspection, requires a qualitative or quantitative assessment of the probability of failure (PoF) and the consequences of failure (CoF) associated with each item of equipment, assemblies or pipelines included in a particular process unit. Properly implemented RBI program allocates individual pieces of equipment according to their risks and gives priority to inspection based on this categorization.

The ISO 31000 (Risk management - Guidelines) standard (5) defines risk management and its assessment methodology. This standard has performed a number of applied risk-based concepts, such as Quantitative Risk Assessment (QRA), Risk-Based Control (RBI), Risk-Based Control and Maintenance (RBMI), Reliability-Based Maintenance (RCM), Risk-based age management (RBLM), or simply, Risk-based management (RBM).

Standard ISO 31010 Risk management - Risk assessment techniques defines risk management, and one of the important phases is risk analysis. Cause analysis identifies risks and causes, as well as their relationship, i.e. the impact of causes on risk, assesses the probability and consequences of risk realization, proposes measures for their elimination, defines parameters for monitoring and more. The ISO 31010 standard (6) is an auxiliary standard for ISO 31000 and provides guidance on the selection and application of systematic risk assessment techniques. A risk assessment conducted in accordance with this standard contributes to other risk management activities.

Other international engineering standards dealing with this issue are: API 571: Dam-age Mechanisms Affecting Fixed Equipment in the Refining Industry (7), API 580: Risk-Based Inspection - Recommended Practice (8), API 581: Risk Based Inspection Methodology - Recommended Practice (9) and ASME PCC-3: Inspection Planning Using Risk-Based Methods (10).

Risk-based inspection (RBI) is a method in which assets are identified for inspection based on their associated risks, as opposed to a predetermined time interval. In other words, it is a planning and prioritization tool, predominantly used in the oil and gas industry, that helps identify high-priority items (i.e., high-risk ones) relative to low-priority items (i.e., high-priority items). Those with low risk). This approach allows users / property owners to increase the efficiency of their inspection resources by concentrating them on those assets that pose the greatest risk and do not spend resources on assets that have essentially no impact.

In a risk-based inspection, the risk is calculated as a result of the probability of failure and the consequences associated with the failure.

Risk = probability of failure x consequences of failure

Risk is usually considered a better measure of priority than the probability of failure or the consequences of failure individually, because it describes the actual damage or loss more. For example, if you have to determine the advantage of two assets where one asset has a high probability of failure but a low consequence of failure and the other asset has a low probability of failure but a high consequence of failure, the analysis will give completely opposite results if you consider only one or the other factor. The use of risk eliminates this ambiguity. The probability of failure (POF) is determined using the applicable damage factors (mechanisms), the frequency of generic failures and management system factors (10):

$$POF(t) = 1 - e^{-gff \times FMS \times Df(t)}$$

where: gff is the generic failure frequency, FMS is the control system factor and Df (t) is the overall failure factor.

The frequency of generic failures is based on industry averages of equipment failures. The management system factor is a measure of how well the plant's management and workforce are trained to handle the plant's day-to-day activities and any emergencies that may arise due to an accident. Total damage factor is a combination of different damage factors that are applicable to a particular piece of equipment being analyzed. The consequence of a failure is calculated as a combined value of the consequences of damage to damaged equipment, damage to surrounding equipment, loss of production, costs due to injury per person and damage to the environment. The consequence of a failure may include both a financial consequence (FC) and an area safety (CA) consequence (10).

Some of the pressure equipment that requires a special program of periodic inspection due to the specifics of construction or operating conditions are: pressure equipment in electrical switches and switchgear, fire protection devices, pressure equipment operating in a closed circuit, silencers, equipment under pressure intended for fire extinguishing, pressure equipment with outer shell or wall, pressure equipment for gases and gas mixtures operating at temperatures below -10ºC and others.

3 Special program for periodic inspections of the oil / nitrogen membrane pressure accumulator

3.1 Technical characteristics of the membrane pressure accumulator

Figure 1 shows a membrane oil / nitrogen pressure accumulator, manufactured by HYDAC Tech-nology GmbH, D-66280 Sulzbach / Saar, Germany. The technical characteristics of this vessel are listed in Table 1.

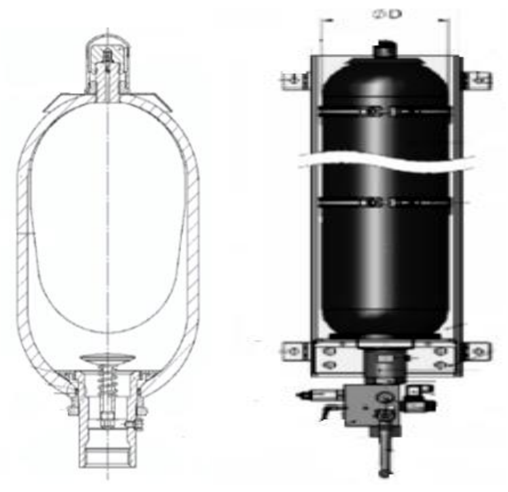

Figure 1. Membrane pressure accumulator

Table 1. Operating characteristics of a membrane pressure accumulator

Operating parameters		Unit	Value
Max allowed working pressure	PS	[bar]	330
Test pressure	PT	[bar]	472
Volume	V	[l]	10
Max allowed working temperature	TS	[°C]	100
Working fluid		-	Oil/nitrogen
Category of the pressure vessel			IV

The category of a membrane pressure accumulator is determined according to diagram 2 in (3) and belongs to the equipment of high level of danger: IV category. According to Annex III - Deadlines for regular periodic inspections, Ordinance on inspection of pressure equipment during the service life (3), the membrane accumulator should be tested according to the following dynamics: for 2 years external inspection, for 5 years internal inspection and for 10 years pressure test.

The problem that arises is the complexity of the construction in which there are no conditions to do an internal inspection or pressure test. Internal inspection can be replaced by ultrasonic measurement of wall thickness, while pressure testing by an equivalent non-destructive testing method. Considering that the accumulator is made of a seamless pipe and that there are no welded joints, it is reduced that the pressure test should be replaced by ultrasonic measurement of the wall thickness, ie two tests should be replaced by the same method. For these reasons, a special testing program is needed to conduct a risk analysis.

3.2 Risk analysis of the membrane pressure accumulator

Risk assessment can be quantitative, which requires a complicated procedure based on a large number of input data, or qualitative, which is reduced to assessing the degree of risk of individual components and their positioning in the risk matrix. Although the results are not as accurate as in the quantitative analysis, this approach is fully justified for pressure equipment where the operating conditions are such that there is virtually no risk of corrosion (stored medium is nitrogen / oil) and brittle fracture (negligible risk of pressure overload). In addition, in the case of the analyzed equipment under pressure for regulating the turbine plant, there are no mechanisms to reduce the wall thickness, especially if we keep in mind that the equipment is seamless, i.e. there are no welded joints, so the probability of failure is practically zero which is confirmed by history of such plants. Accordingly, the position in the risk matrix depends only on the estimated consequence, which in the worst case would be field B1, Table 2, i.e. (very) low risk.

Table 2 shows Numerical Values Associated with POF and Area-Based COF Categories taken from API 581 (9). Consequence area for this accumulator is 25m^2 and damage factor is 1. Based on these data and according to Table 2 the membrane pressure accumulator belongs to B1 category, i.e. low risk.

Table 2. Numerical Values Associated with POF and Area-Based COF Categories (9)

Cate-gory	Probability Category		Consequence Category	
	Probability Range	Damage Factor	Range Category	Range (m2)
1	Pf (t) ≤ 3.06E-5	Df ≤ 1	A	CA ≤ 9.29
2	3.06E-5 < Pf(t) ≤ 3.06E-4	1 < Df ≤ 10	B	9.29 < CA ≤ 92.9
3	3.06E-4 < Pf(t) ≤ 3.06E-3	10 < Df ≤ 100	C	92.9 < CA ≤ 929
4	3.06E-3 < Pf(t) ≤ 3.06E-2	100 <Df ≤ 1000	D	929 < CA ≤ 9290
5	Pf (t) >3.06E-2	Df > 1000	E	CA > 9290

Figure 2 presents Iso-Risk Plot for Consequence Area taken from API 581 (9). The values in this iso-risk plot are given in ft^2 and CA for this case is 269 $ft^{2,}$ damage factor is 1, and the accumulator is in field B1, marked with the “X”.

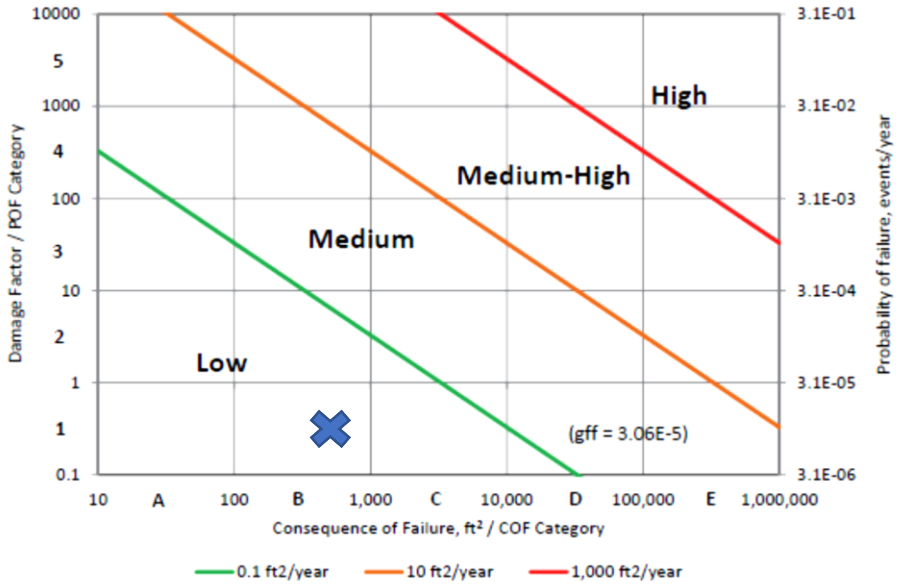

Figure 2. Iso-Risk Plot for Consequence Area (9)

Table 3 shows Numerical Values Associated with POF and Financial-Based COF Categories taken from API 581 (9). Financial risk for this accumulator is below 10000$ and damage factor is 1. Based on these data and according to Table 3 the membrane pressure accumulator belongs to A1 category, i.e. very low risk.

Table 3. Numerical Values Associated with POF and Financial-Based COF Categories (9)

Cate-gory	Probability Category		Consequence Category	
	Probability Range	Damage Factor	Range Category	Range ()
1	$P_f(t) \leq 3.06E\text{-}5$	$D_f \leq 1$	A	$FC \leq 10000$
2	$3.06E\text{-}5 < P_f(t) \leq 3.06E\text{-}4$	$1 < D_f \leq 10$	B	$10000 < FC \leq 100000$
3	$3.06E\text{-}4 < P_f(t) \leq 3.06E\text{-}3$	$10 < D_f \leq 100$	C	$100000 < FC \leq 1000000$
4	$3.06E\text{-}3 < P_f(t) \leq 3.06E\text{-}2$	$100 < D_f \leq 1000$	D	$1000000 < FC \leq 10000000$
5	$P_f(t) > 3.06E\text{-}2$	$D_f > 1000$	E	$FC > 10000000$

Figure 3 presents Iso-Risk Plot for Financial Consequence taken from API 581 (9). The values in this iso-risk plot are given in $ and FC for this case is 1000$ and damage factor is 1, and the accumulator is in field A1, marked with the “X”.

The risk matrix is presented in Figure 4, and fields related to the membrane pressure accumulator are marked with “X”.

This assessment is also influenced by the fact that the risk of accident is lower than the risk of testing, i.e. discharge of this type of pressure equipment, even when controlled, could cause severe consequences.

For this level of risk, the prescribed program for measuring wall thickness every 5 years is conservative because it prevents all possible adverse events and ensures safe operation of the plant.

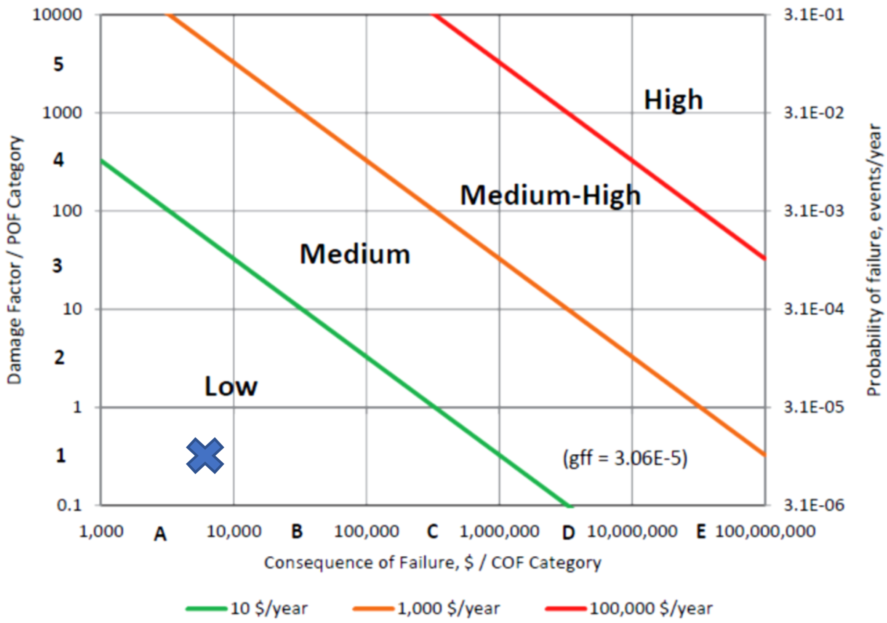

Figure 3. Iso-Risk Plot for Financial Consequence (9)

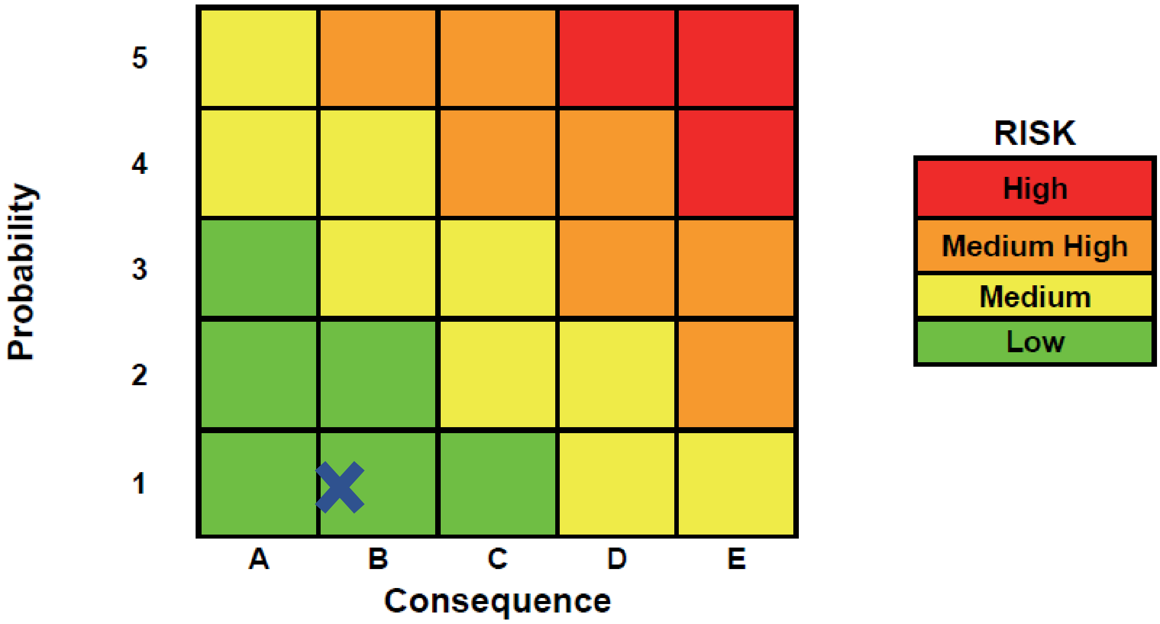

Figure 4. Risk matrix

3.3 Determining the periodicity of subsequent inspections according to the Special Program

External inspection (every 2 years) according to the inspection period assigned in the Ordinance on inspection of pressure equipment during the service life (3).

Visually inspect every two years to check:

- whether there are irregularities and deviations in relation to the technical documentation,
- general condition of membrane accumulator, condition of the supporting structure, connections, accompanying pipelines and safety devices,
- condition of the working environment and plant in which the equipment is located,
- anti-corrosion protection of external surfaces of equipment,
- whether the equipment is used in accordance with the purpose.

Ultrasound wall thickness measurement (every 5th year)

Measurement of wall thickness by ultrasound of cylindrical shells of membrane pressure accumulator should be performed every five years according to the schema given in Figure 5.

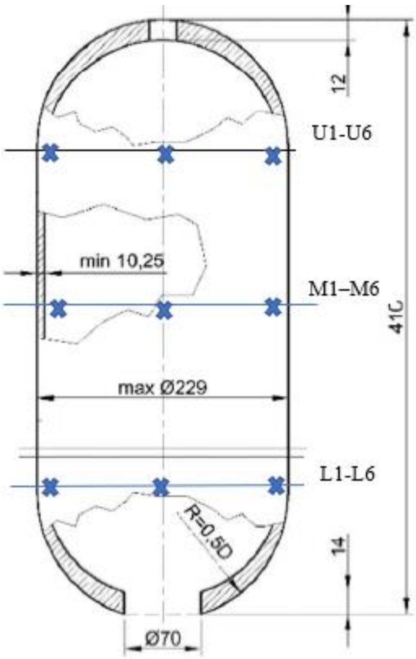

Figure 5. Measuring points U1-U6, M1-M6 and L1-L6 on the membrane accumulator

The minimum wall thickness of the seamless cylindrical shells of membrane pressure accumulators according to the strength calculation is 10.25 mm.

Table 3 gives the results of ultrasound measuring the wall thickness at the measuring points shown in Figure 5.

Table 3. Results of ultrasound measurement of the wall thickness

Point of measurement / Line of measurement	1	2	3	4	5	6
U	11, 3	11, 2	11, 3	11, 3	11, 1	11, 1
M	11, 1	11, 4	11, 2	11, 1	11, 1	11, 4
L	11, 3	11, 3	11, 1	11, 2	11, 2	11, 2

The minimum measured wall thickness of seamless cylindrical shells of membrane pressure accumulators must not be less than the minimum wall thickness as required by the manufacturer and the required wall thickness given in the strength calculation. The derived wall thickness of the lower and upper hemispherical bottom is from 10.25 to 14 mm. The membrane pressure accumulator has no welded joints. Due to the operating conditions, the working medium and the large difference between the required and derived wall thickness, it is not necessary to measure the wall thickness of the lower and upper hemispherical bottoms of membrane accumulators.

4 Conclusion

This paper presents and explains the importance of risk analysis in the preparation of inspections and tests of pressure equipment according to a special program.

The paper presents an example of risk analysis and test periodicity for membrane pressure accumulators.

It has been shown that the risk of accidents is very small and that tests can be performed for 5 years, which would save money.

The risk analysis showed that no critical high risk positions were observed, and that none of the elements of membrane accumulator tends to move to the category of higher risk in the case when the review and testing program is realized in the next review and testing dates given in this program.

5 Reference

[1] *** Rulebook on technical requirements for design, manufacture and conformity assessment of pressure equipment, Official Gazette RS, 87/2011, 2011

[2] *** DIRECTIVE 2014/68/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment, Official Journal of the European Union, 2014

[3] *** Rulebook on inspections of pressure equipment during the service life, Official Gazette of RS, 87/2011 i 75/2013

[4] *** Ordinance on the inspection and testing of pressure equipment, Official Gazette of Croatia, 80/2013 i 14/2014

[5] *** ISO 31000: 2018 Risk management – Guidelines, International Organization for Standardization, 2018.

[6] *** IEC 31010: 2019, Risk management – Risk assessment techniques, International Organization for Standardization, 2019.

[7] *** API 571: Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, American Petroleum Institute, 2020.

[8] *** API 580: Risk-Based Inspection - Recommended Practice, American Petroleum Institute, 2016.

[9] *** API 581: Risk Based Inspection Methodology - Recommended Practice, American Petroleum Institute, 2016.

[10] *** ASME PCC-3: Inspection Planning Using Risk-Based Methods, The American Society of Mechanical Engineering, 2017.