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Inspection scheduling decision model at CNG charging station using risk-based inspection (RBI) method

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Abstract

Most of the transportation industry is still dependent on fossil fuels. The use of fuel oil in the transportation industry has a negative impact on environmental pollution because fuel oil contains CO_2. With the increasing use of fuel oil and environmental pollution problems, Compressed Natural Gas (CNG) is now being developed in the transportation industry. When compared to fuel oils such as gasoline, diesel, and Liquified Petroleum Gas (LPG), CNG emits less harmful gas during combustion. CNG distribution requires a storage device, namely a buffer storage tank which is a closed vessel to accommodate liquids and gases with different temperatures and pressures according to environmental conditions. Buffer storage tanks have a very large risk of accidents including leaks that pose a hazard of fire, explosion, and environmental pollution, which has an impact on technical and financial aspects. Seeing the risks posed by the buffer storage tank, it is necessary to take precautions, inspections, and maintenance to minimize the risk of accidents. The results are the Probability of Failure value based on Art was 1, Leakage Risk Assessment was 247.87 ft^2, and Economic Consequence was $199,514.04. Based on the results of risk analysis referring to API RBI 2008 for CNG buffer storage tanks, it means that leakage consequences are 1B (low risk) and the risk value for economic consequences is 1C (medium). The remaining life of the CNG buffer storage tank shell section is 10.14 years, and that of the head section is 10.42 years. This research is expected to be able to produce an appropriate inspection scheduling decision model for CNG buffer storage tanks and recommendations for preventive actions based on leakage risk and financial aspects.

Keywords

CNG charging station, RBI method, Fuel oils

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Introduction

The increasing number of motorized vehicles in the transportation sector has a negative impact on the environment and contributes to pollution. The trend of increasing the number of motorized vehicles continues to experience a very significant increase. In 2018 the number of motorized vehicles was 126,508,776 units and in 2020 it has increased to 136,137,451 units [1]. Motor vehicle engines produce carbon dioxide gas (CO_2) during the combustion process. This makes the transportation industry the second largest contributor to Greenhouse Gas (GHG) emissions after the manufacturing industry based on the Study of the Use of Tier 2 Local Emission Factors [2].

Most of today's transportation still depends on the use of fossil fuels. The use of fuel oil for motor vehicles is currently inversely proportional to the oil reserves explored in Indonesia. The availability of petroleum is decreasing for domestic needs and must be imported [3]. Based on statistical data released by the Ministry of Energy and Mineral Resources, national oil reserves for the 2016 period were 3.31 thousand MMSTB and in 2020 decreased to 2.44 thousand MMSTB [4]. This shows that the amount of national oil reserves continues to decline due to the increasing use of fuel oil.

Seeing these conditions required alternative fuels that are environmentally friendly as a substitute for fuel oil. Currently, alternative fuels are being developed due to the increasing use of fossil-based fuels and environmental problems, one of which is Compressed Natural Gas (CNG). CNG emits less harmful gases such as CO2 during the combustion process than vehicles that use fuel oil. CNG has three main reasons to be used as an alternative energy substitute for fuel oil including its impact on the environment and humans, relatively cheap price, and energy security. Therefore, CNG can be seen as a transitional fuel to renewable and cleaner sources [5].

The availability of CNG supplies is increasing worldwide, but this requires a good distribution infrastructure. In its distribution, CNG requires a storage device, namely a buffer storage tank which is a closed vessel to accommodate liquids and gases with different temperatures and pressures according to environmental conditions [5]. Buffer storage tanks have drawbacks, namely the walls to cover parts of the tank are susceptible to corrosion, which is the result of vessels working at high pressure [6]. The impact of losing the retaining wall on the pressure vessel results in a leak that can trigger a fire, explosion, environmental pollution, and impact financial losses.

There have been many explosions caused by tanks and gas distribution networks, including in Northern British Columbia when four vacuum trucks were cleaning two pressure vessels that had been filled with sand and liquid. During operations, an explosion occurred inside one of the vessels being depressurized for cleaning, one worker was seriously injured, and two others received serious burns [7]. Then the explosion at a Compressed Natural Gas (CNG) filling station in India killed one employee and two people were seriously injured. The cause of the explosion is not yet known, the police are still scanning CCTV footage to uncover the cause of the explosion [8]. On April 3, 2017, an explosion occurred at the Loy-Lange Box Company in St. Louis, Missouri. The incident occurred when the lower head of a pressure vessel called a semi-enclosed receiver failed. Pressure vessel failure caused a Boiling Liquid Expanding Vapor Explosion (BLEVE) which fatally injured an employee and launched the pressure vessel into the air [9]. The explosion incident and failure of the CNG pressure vessel can be seen in Figure 1.

Figure 1. Effects of CNG pressure vessel explosions in: (a) Canada; (b), India, and (c) USA

Previous research related to mitigating oil and gas leaks includes research conducted by Y. Li et al., entitled Risk Analysis and Maintenance Decision Making of Natural Gas Pipelines with External Corrosion Based on Bayesian Network. The purpose of this study is to identify the causes of external corrosion and carry out special maintenance measures. The methods used are Fault Tree Model, Probability Estimation Model, and Bayesian Network. The results show that the method proposed in this work can provide effective treatment schemes for different pipe external corrosion scenarios and reduce the possible losses caused by external corrosion [10]. Research conducted by B. Xin et al. entitled Dispersion Characteristics and Hazard Area Prediction of Mixed Natural Gas Based on Wind Tunnel Experiments and Risk Theory. The purpose of this research is to take into account the frequency of accidents and the nature of the purpose of protection. The method used is Computational Fluid Dynamics (CFD) and Risk Theory. The research results show that wind speed, wind direction, topography, and their interactions have an important influence on the dispersion process and the Mixed Natural Gas (M-NG) hazard area [11]. Research conducted by S. He et al., entitled Risk Assessment of Oil and Gas Pipelines Hot Work Based On AHP-FCE. The aim of this study was to evaluate the risk of single hot work in the springs of a single natural gas pipeline in a high-consequence area. The methods used are Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE). Based on the results of the questionnaire, AHP was used to calculate the evaluation indicator weight coefficient, and FCE was used to evaluate the risk level of hot work. Once calculated, the hot work total risk score is 40.888. This method can not only quantitatively evaluate the risk level of hot work, but also reasonably rank the importance of various risk factors [12]. Research conducted by L. Kraidi et al. entitled An Investigation of Mitigating the Safety and Security Risks Allied with Oil and Gas Pipeline Projects (OGP). The aim of this research is to develop a risk management system based on a holistic approach to identify, analyze, and rank related Risk Factors (RFs). The methods used are Risk Mitigation Methods (RMMs) and Qualitative Analysis. Based on the survey results, the probability and severity levels of RFs are used as inputs for a computer-based risk analysis model. The model uses fuzzy theory to assess the probability and consequence level of RFs and ranks them in terms of their impact on the project. The results reveal that terrorism, official corruption and unsafe areas are the most critical risks. Similarly, RMMs are evaluated based on their level of efficacy for reducing risk in OGP projects [13]. Research conducted by Y. Zhang et al. entitled Advanced Monitoring and Simulation for Underground Gas Storage Risk Management. The aim of this research is to equip Underground Gas Storage (UGS) operators with real-time monitoring data and simulation tools that can alert them to potential failures, detect leaks early, and support mitigation decision making to prevent larger failures. The method used is the Integrated Risk Management and Decision Support System (IRMDSS). Results of a review of Distributed Temperature Sensing (DTS) data collected at operating UGS facilities indicate that DTS can identify the depth of water gas contact in the good annulus and DTS can provide an early warning signal of upward gas flow as would occur in a well blowout scenario. When combined with modelling analysis, crude leakage rates can be roughly estimated to understand the severity of leakage conditions and to support the necessary mitigation decisions [14].

Seeing the risks posed by gas storage devices, it is necessary to take preventive, maintenance, and inspection measures to minimize the occurrence of hazards. For this reason, this study proposes a calculation model using a tool that has been developed based on the RBI method with the API 581 standard in analyzing the level of risk of leakage and the economic consequences of CNG buffer storage tanks.

Method

The object of this study is a CNG buffer storage tank used by an oil and gas company in Indonesia. The data collection scheme is illustrated in Figure 2. The inspection layout of the CNG buffer storage tank consists of a shell and a head, each of which is subdivided into 5 measurement points. Each shell and head were examined at three points between 90, 180, and 270-degree angles. The inspection method for measuring CNG pressure vessel conditions used is usually the effective category, which has a confidence level of 60% to 80% and a nominal 20% coverage of ultrasonic manual scanning.

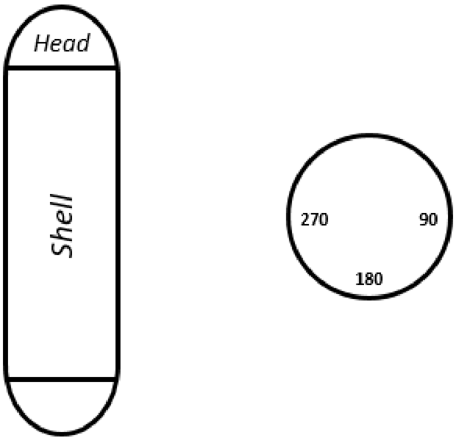

Figure 2. Inspection setup for CNG buffer storage tank

Based on the dummy data, data processing is performed to calculate the risk rating of the CNG buffer storage tank using a semiquantitative method based on API 581. Beginning with calculating the PoF value determined from two components, namely the generic frequency of failure and the damage factor of the CNG buffer storage tank. Next, the CoF leakage and economic values are calculated for the CNG buffer storage tank. The calculation of CoF leakage is limited to area consequences only. Calculation of economic CoF is determined by calculating the cost of damage around the unit, calculating the cost of cleaning the environment, calculating the cost of component damage, calculating the cost of injury to personnel, calculating the cost of lost production in units, calculating the cost of lost production in units. Based on the PoF and CoF values that have been obtained, the risk rating of the two pieces of equipment is determined. Known PoF and CoF values are converted using a conversion table. After obtaining the risk level, the residual life of the CNG buffer storage tank is calculated so that the proper treatment for the equipment being evaluated can be identified.

Based on dummy data, the CNG buffer storage tank has a vertical separator type. The latest thickness of the CNG buffer storage tank on the shell is 6.20 mm and on the head is 6.10 mm. The previous thickness of the CNG buffer storage tank on the shell and head was 6.70 mm. The CNG buffer storage tank has an internal diameter of 254 mm and a material length of 998.22 mm. The CNG buffer storage tank was built in 2011. The corrosion allowance of the CNG buffer storage tank is 0 with a joint efficiency value of 1. The design pressure on the CNG buffer storage tank is 103.89 kg/cm^2. Design temperature of 15 °C. The allowance stress value is 3339.57.

The research process will be carried out by obtaining operational specification data and measuring the CNG wall thickness. Next, calculate the Probability of Failure (PoF) and Consequence of Failure (CoF) values. The consequence value is divided into two, namely the leakage consequence value and the economic consequence value. After obtaining the PoF and CoF values, they are then converted into a risk matrix to find out how big the risk level is. Lastly, calculate the remaining life of the CNG buffer storage tank and analysis of conclusions.

Risk Based Inspection (RBI) is a method that uses risk as a basis for conducting an inspection. RBI is a risk assessment and management process that focuses on the loss of containment from pressure equipment in processing facilities due to material damage [15]. This method categorizes operational equipment based on its level of risk.

The purpose of RBI is to protect equipment by identifying areas that have a high level of risk and estimating the risk value of each equipment. There are priorities based on measurable risk values, designing suitable inspection plans to be carried out systematically, and managing the risk of tool failure [6].

API 581 divides the types of RBI assessments into 3 types of approaches, namely qualitative approaches, semi-quantitative approaches, and quantitative approaches. The qualitative method is a method that analyzes using general categorization for Probability of Failure (PoF) and Consequence of Failure (CoF). The quantitative method is a method that analyzes based on complex data calculations, quantitative risk analysis uses a logical model that describes a combination of events that can cause an adverse accident and a physical model that describes the repair of accidents and the movement of materials that are hazardous to the environment. Meanwhile, the semi-quantitative method is a method in the middle between qualitative and quantitative, where the results achieved are more accurate than qualitative, but the calculations are not as complex as the quantitative method.

RBI is defined as a combination of Probability of Failure (PoF) and Consequence of Failure (CoF). According to API 581, risk can be calculated with the following Eq (1):

$$\text{PoF x CoF} \qquad (1)$$

Results and discussion

Thickness measurement

The latest thickness calculation is simulated using dummy data. A comparison between the initial and current thicknesses can be seen in Figure 3 and Figure 4. The results of T_{actual} and $T_{required}$ thickness values of the head and shell sections can be seen in Table 1.

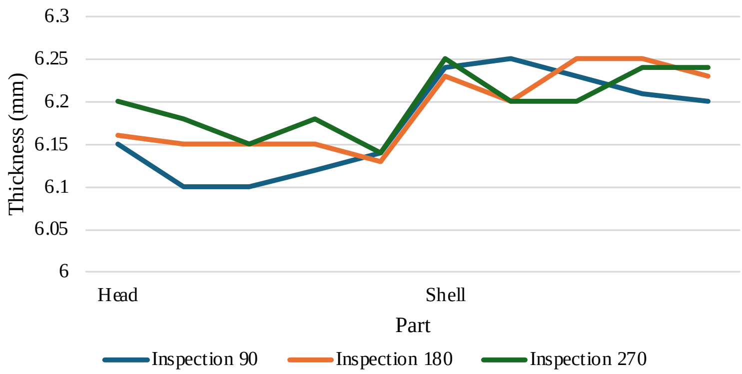

Figure 3. CNG buffer storage tank thickness data

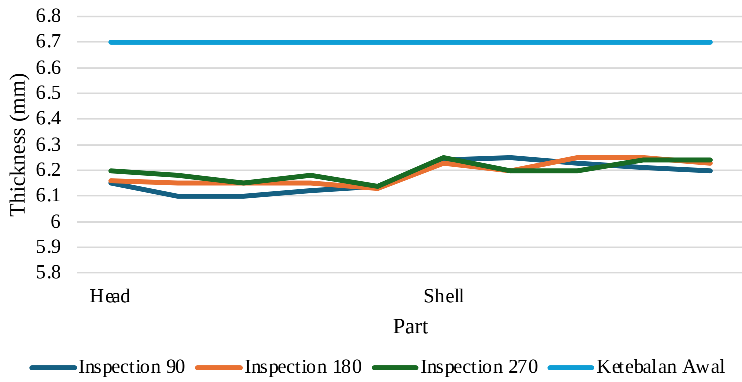

Figure 4. Data comparison between the initial thickness and the current thickness

Table 1. The required thickness calculation results

No.	Part	T_{actual} (mm)	$T_{required}$ (mm)	Result
1.	Head	6.20	5.49	Satisfaction
2.	Shell	6.10	5.37	Satisfaction

Probability of failure (PoF)

The overall failure rate and the damage factor of the item inspected are the two factors used to generate the PoF value according to API 581. The common failure rate (gff) value specified in API 581 is the typical failure value that occurs with an individual device. Failure rates are often determined based on some form of damage resulting in corrosion, erosion, or other types of damage. The first step in calculating the RBI method is determining the PoF value, the calculation system will work using the inspection data that has been obtained previously. The PoF calculation includes the calculation of short corrosion and long corrosion based on the current thickness data, calculation of the damage factor parameter (A_{rt}) and base damage factor $(D_{thin}fb)$, and calculation of the Management System Factor.

In general, the failure frequency is calculated based on various damages that cause corrosion, erosion, and other damage. Based on dummy equipment data, the damage mechanism that occurs is only caused by internal corrosion attack (thinning), while damage mechanisms such as external corrosion, CUI, HTHA, brittle fracture, and fatigue are considered not to occur. Thus, the total damage factor (D_f) of the CNG buffer storage tank is only affected by the thinning value.

The component type of CNG buffer storage tank is KODRUM. Generic failure frequency (gff) values for each leak hole size, namely, small (1/4 in.) has a value of 8 x 10^{-6}, medium (1 in.) has a value of 2 x 10^{-5}, large (4 in.) has a value of 2 x 10^{-6}, and rupture (16 in.) has a value of 3,06 x 10^{-5}. The damage factor calculation results from the CNG buffer storage tank yield a damage factor (A_{rt}) parameter value of 0.64 for the shell section and 0.81 for the head section. The damage factor is caused by thinning and the total damage factor is 1.

Consequence of failure (CoF)

The calculation of the consequences carried out in this study is the calculation of the consequences of the burning area of the equipment. The calculation of these consequences starts from determining the rate of fluid leakage, the amount of fluid that comes out, and calculating the area consequences based on the calculation stages set out in API 581 document.

1. Determine leakage rate

To determine the rate of fluid leakage, it is necessary to know the representative fluid on the inspected equipment. The type of fluid contained in the CNG buffer storage tank is methane gas (C1-C2). Next, the leak rate is calculated for each hole size. The hole sizes used are divided into 4 types, namely small (1/4 in.), medium (1 in.), large (4 in.), and rupture (16 in.). There are two types of gas leakage rates, namely sonic and subsonic which are distinguished based on a comparison of the values of storage pressure (Ps) and transition pressure (P_{trans}). The sonic gas leakage rate has a greater Ps value than P_{trans} and vice versa. The results of the calculation of the release rate value for CNG buffer storage tanks based on the type are small (1/4 in.) of 3.904320399 lbs, medium (1 in.) of 62.46912639 lbs, large (4 in.) of 999.5060222 lbs, and a rupture (16 in.) of 15992.09635 lbs.

2. Determine available fluid mass

It is necessary to know the available fluid mass in inspected equipment to determine the amount of fluid that comes out if a leak occurs in the equipment. The total fluid available in the CNG buffer storage tank is the component fluid mass of 31278 lbs, the total fluid mass is 3070435.648 lbs. The available fluid masses based on the leakage rate are small (1/4 in.) of 31980.77767 lbs, medium (1 in.) of 78464.44275 lbs, large (4 in.) of 247131.084 lbs, and rupture (16 in.) of 2945797.344 lbs.

3. Consequence value

The final stage is to determine the consequences of fires and explosions caused by equipment damage. The consequences that are calculated are the area consequences caused by the burning of the components and the burning of the equipment itself. The consequence area is calculated based on API 581. The final consequence value obtained based on component area consequence (CA_{cmd}^{flam}), component area consequence (CA_{cmd}^{flam}), final failure consequence is 247.87 ft^2

Economic consequence

Based on the API 581 document, the economic consequence calculation includes the cost of damage to the surrounding unit, calculates the cost of environmental cleaning, calculates the cost of component damage, calculates the cost of personnel injuries, calculates the cost of lost production per unit, calculates the cost of lost production per unit.

The basic method for economic consequence analysis as presented in the RBI API is not changed for financial risk analysis. Risk is still calculated as a consequence of failure (expressed as a cost in dollars) multiplied by the probability of failure. The results of the economic consequence calculation in dollars ($) are component damage cost (FC_{cmd}) worth 11,241.83, damage cost surrounding equipment in the affected area (FC_{affa}) worth 77,000, potential lost production cost (FC_{prod}) valued at 104,310.67, potential injury cost (FC_{inj}) valued at 6,961.54, environmental cleanup cost ($FC_{environ}$) valued at 0, and total economic consequence valued at 199,514.04.

Determining the risk rating

The risk rating is determined from the known PoF and CoF values which are then converted using the table of possible failure and consequence categories set out in API 581. The risk value will increase as the PoF and CoF values increase [15]. Based on the calculated PoF and CoF values, a risk value is obtained for the CNG buffer storage tank.

1. Leakage risk assessment

It is known that the value of the damage factor due to depletion or corrosion on the equipment is 1, the PoF conversion result is 1, while the final CoF value obtained is 247.87 ft^2, the CoF conversion result is B (Table 2). So that the buffer storage tank has a risk value of 1B which is in the area of low risk or low risk (Figure 5).

Table 2. Categories of possible failure and consequences of failure

Possible Failure		Possible Failure	
Categories	**Range**	**Categories**	**Range (ft2) *P P***
1	$D_{f-total}$ ≤ 2	A	CA ≤ 100
2	2 ≤ $D_{f-total}$R ≤20	B	100 ≤ CA ≤ 1000
3	20 ≤ $D_{f-total}$R ≤100	C	1000 ≤ CA ≤ 3000
4	100 ≤ $D_{f-total}$ R ≤1000	D	3000 ≤ CA ≤ 10000
5	$D_{f-total}$R ≥ 1000	E	CA ≥ 1000

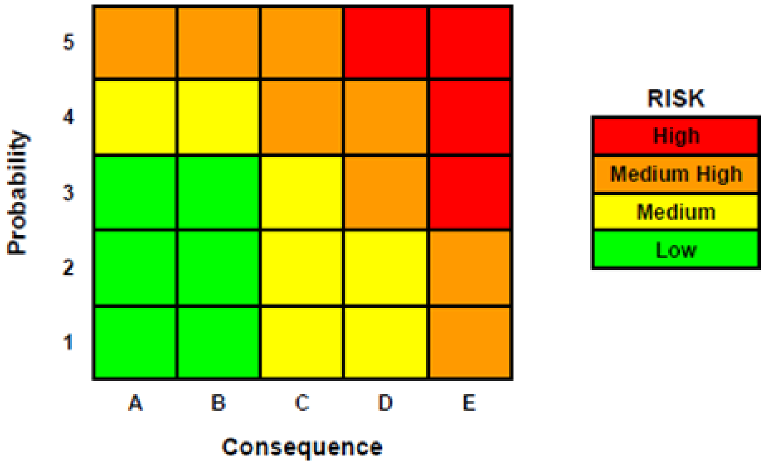

Figure 5. Leakage risk matrix

2. Value of Economic Risk

It is known that the value of the damage factor due to depletion/corrosion of the equipment is 1, the PoF conversion result is 1, while the final economic consequence value obtained is $199,514.04, the economic consequence conversion result is C (Table 3). So that s has a risk value of 1C which is in the medium area risk (Figure 6).

Table 3. Categories of possible failure and economic consequences

Possible Failure		Possible Failure	
Categories	Range	Categories	Range ($) *P P*
1	$D_{f-total} \leq 2$	A	$FC \leq 10000$
2	$2 < D_{f-total} \leq 20$	B	$10000 < FC < 100000$
3	$20 < D_{f-total} \leq 100$	C	$100000 < FC < 1000000$
4	$100 < D_{f-total}$ R ≤ 1000	D	$1000000 < FC < 10000000$
5	$100 < D_{f-total}$ R ≤ 1000	E	$FC > 10000000$

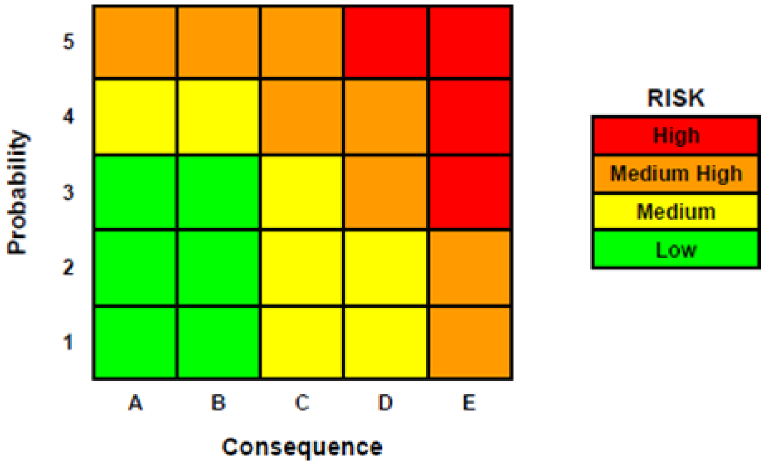

Figure 6. Economic consequence matrix

Calculating remaining age

Residual life calculation is calculated using Eq (2) which is a comparison between the thickness of the material at the time of inspection and the corrosion rate that occurs in the equipment.

$$Remaining\ Life = \frac{t_{actual} - t_{required}}{corrosion\ rate} \quad (2)$$

$$RLS = \frac{t_{actual} - t_{required}}{corrosion\ rate} = \frac{6.20 - 5.49}{0.07} = 10.14 \text{ year}$$

$$RLH = \frac{t_{actual} - t_{required}}{corrosion\ rate} = \frac{6.10 - 5.37}{0.07} = 10.42 \text{ year}$$

Conclusion

Based on the results of risk analysis referring to API RBI 2008 for CNG buffer storage tanks, the result is that the most dominant damage mechanism is the internal damage factor (Df_{thin}). The risk value for leakage consequences is 1B (low risk) and the risk value for economic consequences is 1C (medium). The remaining life of the CNG buffer storage tank shell section is 10.14 years, and the head section is 10.42 years. After analyzing the next inspection schedule for the CNG buffer storage tank is in the next 10 years or in 2033.

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