UDC 621.642.39
CSCSTI 81.81.17
DOI: 10.54859/kjogi108863
Received: 21.04.2025.
Accepted: 07.11.2025.
Published: 31.12.2025.

Original article

Optimizing Re-Inspection Intervals for Aboveground Storage Tanks Utilizing Risk-Based Approach and Advanced Tank Bottom Scanning

Zhanna Ualiyeva[1], Abdugaffor Mirzoev[2]
[1]Kazakh-British Technical University, Almaty, Kazakhstan
[2]ROSEN Europe B.V., Almaty, Kazakhstan

ABSTRACT

Background: Aboveground Storage Tanks (ASTs) are critical assets in the oil and gas sector, where maintaining their structural integrity is essential for operational safety, environmental protection, and cost-efficiency. In Kazakhstan, traditional time-based inspection (TBI) methods dominate, despite their inefficiency and inflexibility. The integration of Risk-Based Inspection (RBI) with advanced Non-Destructive Testing (NDT) technologies offers a promising alternative to optimize inspection intervals and improve asset management, especially considering regulatory limitations and economic pressures that intensified during the COVID-19 pandemic.

Aim: To optimize re-inspection intervals for ASTs in Kazakhstan's oil and gas industry by integrating RBI methodologies with advanced NDT technologies, particularly ROSEN TBIT Ultra, and to compare these with traditional inspection methods.

Materials and methods: RBI methodology outlined in API RP 580 and 581, industrial data for the given tank X.

Results: The integration of RBI and advanced NDT enabled prioritization of high-risk tanks, identification of localized corrosion mechanisms, and optimization of inspection intervals. Compared to the rigid TBI schedule, the proposed approach demonstrated higher inspection efficiency, lower resource wastage, and reduced risk of catastrophic failure, while aligning with global standards and local legal frameworks.

Conclusion: By adopting RBI methodologies supported by technologies like ROSEN TBIT Ultra, Kazakhstan's oil and gas industry can transition from fixed-interval inspections toward a predictive, risk-prioritized approach. This transition supports better asset integrity management, enhances safety, and contributes to long-term infrastructure reliability, especially critical for aging storage systems.

Keywords: *risk-based inspection; ROSEN TBIT Ultra; NIMA Integrity Management; aboveground storage tanks; non-destructive testing; magnetic flux leakage; inspection interval optimization; asset integrity.*

To cite this article:
Ualiyeva Zh, Mirzoev A. Optimizing Re-Inspection Intervals for Aboveground Storage Tanks Utilizing Risk-Based Approach and Advanced Tank Bottom Scanning. *Kazakhstan journal for oil & gas industry.* 2025;7(4):59–71. DOI: 10.54859/kjogi108863.

УДК 621.642.39
МРНТИ 81.81.17
DOI: 10.54859/kjogi108863
Получена: 21.04.2025.
Одобрена: 07.11.2025.
Опубликована: 31.12.2025.

Оригинальное исследование

Оптимизация интервалов повторных проверок надземных стальных резервуаров для хранения с использованием подхода, основанного на оценке риска, и полного сканирования дна резервуара

Ж. Уалиева[1], А. Мирзоев[2]
[1]Казахско-Британский технический университет, Алматы, Казахстан
[2]ROSEN Europe B.V., Алматы, Казахстан

АННОТАЦИЯ

Обоснование. Наземные резервуары являются критически важными объектами в нефтегазовой отрасли, обеспечение их структурной целостности имеет решающее значение для безопасности эксплуатации, охраны окружающей среды и экономической эффективности. В Казахстане по-прежнему преобладают традиционные методы инспекции с фиксированными интервалами, несмотря на их неэффективность и негибкость. Интеграция риск-ориентированной инспекции с передовыми технологиями неразрушающего контроля представляет собой перспективную альтернативу для оптимизации интервалов проверок и повышения эффективности управления активами, особенно в условиях нормативных ограничений и экономического давления, обострившихся во время пандемии COVID-19.

Цель. Оптимизировать интервалы повторной инспекции для наземных резервуаров в нефтегазовой отрасли Казахстана путем интеграции RBI-методологии с современными НК-технологиями, в частности ROSEN TBIT Ultra, и провести сравнительный анализ с традиционными методами инспекции.

Материалы и методы. Методология RBI, изложенная в API RP 580 и 581, а также промышленные данные по конкретному резервуару X.

Результаты. Интеграция RBI и передовых методов НК позволила приоритизировать резервуары с высоким уровнем риска, выявить локализованные механизмы коррозии и оптимизировать интервалы проверок. В сравнении с жестким графиком TBI предложенный подход продемонстрировал более высокую эффективность проверок, снижение потерь ресурсов и уменьшение риска катастрофических отказов в соответствии с международными стандартами и требованиями национального законодательства.

Заключение. Внедрение RBI-методологий с поддержкой таких технологий, как ROSEN TBIT Ultra, позволит нефтегазовой отрасли Казахстана перейти от фиксированных интервалов проверок к прогнозируемому, риск-ориентированному подходу. Такой переход способствует лучшему управлению целостностью активов, повышению безопасности и устойчивости инфраструктуры в долгосрочной перспективе, что особенно актуально для стареющих систем хранения.

Ключевые слова: *риск-ориентированная инспекция, ROSEN TBIT Ultra, NIMA Integrity Management, наземные резервуары, неразрушающий контроль, магнитный потоковый контроль, оптимизация интервалов проверок, целостность активов.*

Как цитировать:
Уалиева Ж., Мирзоев А. Оптимизация интервалов повторных проверок надземных стальных резервуаров для хранения с использованием подхода, основанного на оценке риска, и полного сканирования дна резервуара. 2025. Том 7, №4. С. 59–71. DOI: 10.54859/kjogi108863.

ӘОЖ 621.642.39
ҒТАХР 81.81.17
DOI: 10.54859/kjogi108863
Қабылданды: 21.04.2025.
Мақұлданды: 07.11.2025.
Жарияланды: 31.12.2025.

Түпнұсқа зерттеу

Тәуекелді бағалауға негізделген тәсілді және резервуарлардың түбін толық сканерлеуді пайдалана отырып, жер үсті болат резервуарларының диагностикалық аралық интервалын оңтайландыру

Ж. Уалиева[1], А. Мирзоев[2]
[1]Қазақ-Британ техникалық университеті, Алматы қаласы, Қазақстан
[2]ROSEN Europe B.V., Алматы қаласы, Қазақстан

АННОТАЦИЯ

Негіздеу. Жер үсті резервуарлары мұнай-газ саласындағы маңызды объектілер болып табылады, мұнда пайдалану қауіпсіздігі, қоршаған ортаны қорғау және экономикалық тиімділік үшін олардың құрылымдық тұтастығын қамтамасыз ету өте маңызды. Қазақстанда тиімсіздігі мен икемсіздігіне қарамастан, белгіленген интервалмен инспекциялаудың дәстүрлі әдістері әлі де басым. Тәуекелге бағытталған инспекцияны бұзбайтын бақылаудың озық технологияларымен біріктіру тексеру интервалдарын оңтайландыруға және активтерді басқару тиімділігін арттыруға, әсіресе COVID-19 пандемиясы кезінде шиеленіскен нормативтік шектеулер мен экономикалық қысым жағдайында перспективалы балама болып табылады.

Мақсаты. Қазақстанның мұнай-газ саласындағы жер үсті резервуарлары үшін қайта инспекциялау интервалдарын RBI-әдіснаманы қазіргі заманғы НК-технологиялармен, атап айтқанда ROSEN TBIT Ultra интеграциялау арқылы оңтайландыру және инспекцияның дәстүрлі әдістерімен салыстырмалы талдау жүргізу.

Материалдар мен әдістер. API RP 580 және 581-де көрсетілген RBI әдістемесі, сондай-ақ X резервуарына арналған өндірістік деректер қолданылды.

Нәтижелері. RBI және НК озық әдістерін біріктіру тәуекел деңгейі жоғары резервуарларға басымдық беруге, коррозияның локализацияланған механизмдерін анықтауға және тексеру аралықтарын оңтайландыруға мүмкіндік берді. Қатаң TBI кестесімен салыстырғанда ұсынылған тәсіл халықаралық стандарттар мен ұлттық заңнаманың талаптарына сәйкес тексерулердің жоғары тиімділігін, ресурстардың ысыраптарын азайтуды және апатты істен шығу қаупін азайтқандығын көрсетті.

Корытынды. ROSEN TBIT Ultra сияқты технологияларды қолдай отырып, RBI-әдістемелерін енгізу Қазақстанның мұнай-газ саласына тексерулердің белгіленген интервалдарын болжамды, тәуекелге бағдарланған тәсілге көшуге мүмкіндік береді. Мұндай ауысу активтердің тұтастығын басқаруды жақсартуға, ұзақ мерзімді перспективада инфрақұрылымның қауіпсіздігі мен тұрақтылығын арттыруға ықпал етеді, бұл әсіресе ескі сақтау жүйелеріне қатысты болып отыр.

Негізгі сөздер: *тәуекелге бағытталған инспекция, ROSEN TBIT Ultra, NIMA Integrity Management, жер үсті резервуарлары, бұзбайтын бақылау, магниттік ағынды бақылау, тексеру интервалдарын оңтайландыру, активтердің тұтастығы.*

Дәйексөз келтіру үшін:
Уалиева Ж., Мирзоев А. Тәуекелді бағалауға негізделген тәсілді және резервуарлардың түбін толық сканерлеуді пайдалана отырып, жер үсті болат резервуарларының диагностикалық аралық интервалын оңтайландыру // Қазақстанның мұнай-газ саласының хабаршысы. 2025. 7 том, №4, 59–71 б. DOI: 10.54859/kjogi108863.

Introduction

Aboveground Storage Tanks (ASTs) play a crucial role in industries like oil and gas, chemicals, and agriculture, offering essential storage for liquids and gases. Ensuring the structural integrity of these tanks is vital for operational safety, environmental protection, and cost-effectiveness.

In Kazakhstan, the growth of large-scale storage facilities was raised on a high level during the COVID-19 pandemic, which posed unprecedented challenges to industries globally, with the oil and gas sector being significantly affected. The crisis caused a sharp drop in global demand, resulting in a need to store produced oil, storage overcapacity, and economic stagnation. This period underscored the critical need for robust AST integrity management to safeguard assets during market downturns and to facilitate recovery as global demand rebounded.

Here's a Tab. 1 of AST capacities in cubic meters by country, based on available data. The figures primarily refer to crude oil and petroleum products storage capacities.

Table 1. AST capacities in cubic meters by country

Country	Estimated AST Capacity, million m^3
United States	350–400
China	320–360
India	75–80
Japan	60–70
South Korea	50–60
Netherlands	40–50
Germany	35–45
UAE	30–40
Saudi Arabia	30–35
Singapore	25–30
Russia	25–30
Brazil	20–25
Canada	15–20
UK	10–15
Australia	8–10

Source: statista.com

Optimizing re-inspection intervals is vital for AST reliability. Advanced NDT methods help detect hidden deterioration, reducing failure risks. Combining RBI with techniques like tank bottom scanning improves inspection efficiency, extends asset life, and supports better risk management.

In Kazakhstan, current regulations mandate fixed inspection intervals – for example, every eight years – under the ST RK standard. While this ensures compliance, it doesn't consider dynamic risks like localized corrosion or changing conditions, leading to inefficiencies and missed chances for targeted maintenance[1].

In contrast, the RBI methodology, as outlined in API Recommended Practice 580 [1] and the quantitative framework provided in API Recommended Practice 581 [2], encourages the use of non-invasive inspection techniques that allow for accurate assessment of material condition and damage mechanisms without compromising operational safety. These techniques have been shown to offer superior reliability in detecting localized corrosion, cracking, and other integrity-related anomalies, particularly in corrosion-prone zones of aboveground storage tanks. While the national standard mandates external visual inspection to evaluate the condition of the tank surface, internal visual inspection is generally not considered a standard practice within RBI programs. Instead, advanced non-destructive testing methods, such as MFL, ACFM, Eddy-current, are employed to monitor internal surfaces based on the identified degradation mechanisms, thus minimizing personnel exposure and enhancing inspection efficacy.

In summary, while national regulations in Kazakhstan mandate periodic hydrostatic testing to maintain tank integrity, modern RBI-based approaches – aligned with international standards like API RP 580 and 581 – offer a more efficient, risk-focused strategy. These methods enhance reliability, reduce inspection frequency for low-risk equipment, and support global safety and sustainability goals.

Although RBI is not yet widely implemented

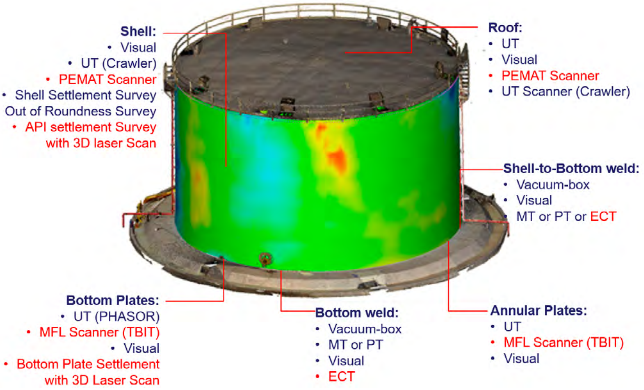


Figure 1. Overview of NDT methods used for AST

In red – advanced NDT methods

---

[1] «Мұнай және мұнай өнімдеріне арналған резервуарларды пайдалану және жөндеу кезіндегі өнеркәсіптік қауіпсіздікті қамтамасыз ету қағидаларын бекіту туралы» Қазақстан Республикасы Төтенше жағдайлар министрінің 2021 жылғы 15 маусымдағы № 286 бұйрығы. Қазақстан Республикасының Әділет министрлігінде 2021 жылғы 17 маусымда № 23068 болып тіркелді.

in Kazakhstan, the legal framework for its adoption exists. Resolution No. 717 (December 30, 2011)[2], provides a methodology for risk assessment in state control and supervision, laying the groundwork for risk-based practices. However, practical application of RBI remains limited and is still evolving across industries.

A major challenge is demonstrating the clear benefits of RBI and advanced inspection technologies over traditional time-based methods. This calls for in-depth analysis and field validation to prove their value in optimizing inspection schedules, improving safety, cutting operational costs, and maintaining regulatory compliance.

Numerous studies highlight the effectiveness of RBI in international settings. One notable example is the Kuwait Oil Company (KOC), which successfully transitioned from fixed-interval inspections to a structured RBI approach aligned with API RP 581 and NFPA guidelines. KOC classified tanks by risk level, identified key damage mechanisms – such as bottom plate corrosion and roof integrity issues – and adjusted inspection intervals based on risk. This shift enabled KOC to prioritize critical tanks, optimize inspection resources, and enhance overall asset integrity. The case demonstrates how RBI can improve maintenance planning and operational efficiency in large-scale industrial operations [3].

However, in Kazakhstan, there is a lack of officially published studies on the application of RBI to ASTs. Addressing this gap is essential for ensuring the long-term reliability and efficiency of the country's storage tank infrastructure – especially as aging facilities and changing operational conditions call for a more strategic approach to risk management. The OECD's Risk Governance Scan of Kazakhstan also underscores this need, pointing to shortcomings in the country's disaster risk management frameworks and emphasizing the importance of forward-looking, risk-informed planning to enhance infrastructure resilience [4].

The objective of the study is to compare re-inspection intervals for ASTs in Kazakhstan by employing an RBI framework complemented by advanced NDT methods, such as the TBIT Ultra technology. By addressing these factors within the context of Kazakhstan's industrial and regulatory landscape, the study aims to provide a comprehensive framework for improving AST inspection practices while balancing safety, environmental stewardship, and economic viability.

Materials and methods

The RBI methodology applied in this study offers a structured approach to prioritize inspection and maintenance of ASTs by assessing the Probability of Failure (PoF) and Consequences of Failure (CoF). These two factors define the overall risk level, guiding decisions on inspection intervals, techniques, and repairs. This approach aligns with API RP 580 and 581, which provide industry-recognized frameworks and quantitative tools for risk-based inspections in oil, gas, and petrochemical sectors.

In practice, a small portion of equipment often accounts for the majority of risk. RBI enables teams to focus resources on high-risk tanks while optimizing efforts for lower-risk ones. It involves identifying degradation mechanisms, linking them to potential failures, and developing targeted inspection plans. API RP 581 offers quantitative methods to evaluate PoF and CoF, enabling data-driven risk ranking and planning.

Unlike Kazakhstan's current prescriptive model (e.g., ST RK standards), which mandates fixed-interval inspections, RBI allows for condition-based prioritization. Adopting RBI in line with API standards would enhance safety and cost-efficiency in managing storage tank infrastructure.

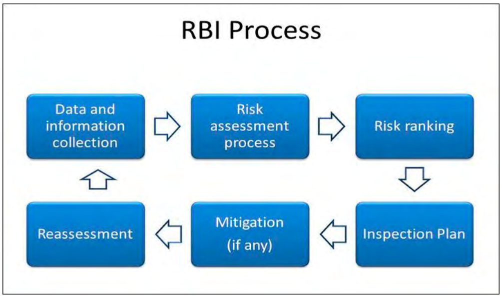


Figure 2. RBI process [5]

Integration of NIMA Integrity Management (IM) Software

In my work, I utilized NIMA Integrity Management (IM) software as a core tool for implementing RBI methodologies. Developed by ROSEN, NIMA is an integrated platform that supports data-driven asset integrity management by consolidating, visualizing, and interpreting large volumes of inspection and operational data. It enables comprehensive risk assessments by integrating in-line inspection results, material properties, degradation mechanisms, and historical performance trends.

The software played a vital role in processing inspection data, performing quantitative risk calculations, and supporting predictive modeling to assess both PoF and CoF. This allowed for dynamic adjustment of inspection intervals based on evolving risk factors, improving planning efficiency and resource allocation.

Within this study, NIMA IM provided a structured framework for evaluating asset integrity, aggregating inspection data, and generating risk matrices to prioritize high-risk equipment. By automating the correlation between degradation mechanisms, failure probabilities, and inspection schedules, the software enhanced consistency, reduced sub-

---

[2] Совместный приказ Министра нефти и газа Республики Казахстан от 25 августа 2011 года № 149 и и.о. Министра экономического развития и торговли Республики Казахстан от 31 августа 2011 года № 272. Зарегистрирован в Министерстве юстиции Республики Казахстан 12 сентября 2011 года № 7177 «Об утверждении критериев оценки степени риска в сфере частного предпринимательства в области проведения нефтяных операций».

jectivity, and improved the accuracy of risk assessments.

Additionally, NIMA IM served as a centralized database for managing inspection histories, corrosion data, and maintenance records, ensuring compliance with API RP 580 and API RP 581 standards and facilitating audit readiness [6].

The use of NIMA IM is particularly valuable in contexts where infrastructure is aging and regulatory pressure for risk transparency is increasing, such as in Kazakhstan. In this regard, NIMA not only supports operational reliability but also strengthens strategic risk governance and sustainability in asset-intensive industries.

Risk Calculation and RBI Framework

Below is an overview of the key criteria and algorithms used in risk calculation within the RBI framework:

Probability of Failure (PoF): PoF is determined by factors such as corrosion rates, environmental conditions, and the effectiveness of protective measures like coatings and cathodic protection. Tools like the TBIT Ultra system enhance accuracy by quantifying metal loss and detecting critical defects.

Consequence of Failure (CoF): CoF measures the potential impact of tank failure, including downtime, environmental damage, safety risks, and financial loss. Tanks storing hazardous or volatile substances – like gasoline in floating roof tanks – have higher CoF due to fire, explosion, or vapor release risks. Environmental regulations also raise the significance of CoF due to spill prevention requirements.

Risk Calculation. Risk is calculated using the formula (1):

$$\text{Risk} = \text{PoF} \times \text{CoF} \tag{1}$$

A risk matrix (Fig. 3) visually categorizes equipment into risk levels – low, medium, high, or critical – based on PoF and CoF. This matrix supports prioritization of inspections and optimized maintenance planning. High-risk tanks require immediate action, while low-risk tanks may have longer inspection intervals.

By combining qualitative and quantitative assessments, the RBI method improves safety, reduces costs, and enhances operational efficiency through targeted, risk-driven inspections [7].

Time-Based vs. Risk-Based Approach

Historically, time-based inspection protocols have been the primary method for monitoring ASTs. Tab. 2 below outlines the regulated intervals for key maintenance and inspection activities for vertical ASTs under this approach. Unlike RBI, the time-based method schedules tasks at fixed intervals, regardless of the equipment's actual risk level. These standards guide maintenance practices for storage tanks in Kazakhstan and support operational planning at industrial sites.

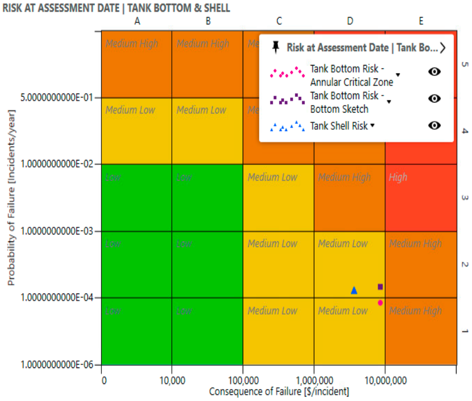


Figure 3. Example of Risk matrix generated in NIMA Integrity Management Software

Table 2. The industry standards timeframes in Kazakhstan[3]

No	Activities	Terms of Work	List of Works to Be Performed
1	Protection Systems	Inspections every 6 months; maintenance annually.	Maintain lightning, corrosion, and static electricity protections.
2	Automated Control Systems	Tested every 2 years; upgraded as needed.	Ensure functionality of automated systems, including diagnostics and software updates.
3	Tank Cleaning	Conducted every 3–5 years or as required based on sediment accumulation.	Perform degassing, sediment removal, and safety cleaning of reservoir interiors.
4	Technical Diagnostics	Detailed diagnostics every 8 years or after major incidents.	Inspect tank walls, foundations, and operational systems using technical tools.
5	Repair Works	Repairs carried out as needed; major overhauls every 10 years.	Perform welding, component replacements, and defect management with certified techniques.

---

[3] СТ РК 3731-2021. Промышленность нефтяная и газовая. Техническое освидетельствование оборудования с учетом факторов риска

According to the Standard of the Republic of Kazakhstan ST RK 3731–2021 titled “Oil and gas industry. Technical inspection of equipment based on risk factors”, the determination of inspection intervals under the RBI methodology is directly linked to the calculated risk level of the equipment. This standard emphasizes that inspection frequency should be based on maintaining an acceptable risk level for each corrosion circuit or equipment item, rather than following fixed, prescriptive intervals. The RBI approach provides a flexible yet structured framework, where the higher the risk level, the shorter the inspection interval, ensuring that critical equipment is monitored more frequently while low-risk equipment can be inspected less often without compromising safety or reliability.

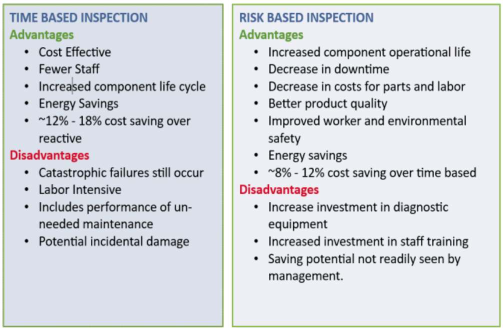
Tab. 3 below presents the recommended inspection intervals in accordance with ST RK 3731–2021, reflecting the principle that inspection efforts should be proportionate to the identified risk levels:

Table 3. Recommended Inspection Intervals under RBI

Risk Level	Inspection Interval (Years)
Negligible Risk	Up to 12 years
Low Risk	6–10 years
Medium Risk	4–6 years
Moderately High Risk	3–4 years
High Risk	2– 3 years

However, traditional time-based methods often overlook variable risk factors affecting tank performance, leading to inefficient resource use and higher integrity risks. In contrast, RBI aligns inspections with actual risk levels, improving efficiency by up to 20% over conventional approaches. This is achieved by focusing resources on high-risk equipment, where they have the most impact. Advanced NDT techniques like ultrasonic testing further strengthen RBI by targeting critical vulnerabilities such as tank bottom corrosion and roof seal issues, enhancing the detection and monitoring of potential failures.

Table 4. Comparison of TBI and RBI



TIME BASED INSPECTION

Advantages
- Cost Effective
- Fewer Staff
- Increased component life cycle
- Energy Savings
- ~12% - 18% cost saving over reactive

Disadvantages
- Catastrophic failures still occur
- Labor Intensive
- Includes performance of un-needed maintenance
- Potential incidental damage

RISK BASED INSPECTION

Advantages
- Increased component operational life
- Decrease in downtime
- Decrease in costs for parts and labor
- Better product quality
- Improved worker and environmental safety
- Energy savings
- ~8% - 12% cost saving over time based

Disadvantages
- Increase investment in diagnostic equipment
- Increased investment in staff training
- Saving potential not readily seen by management.

Unlike traditional time-based inspections, RBI prioritizes inspections based on risk assessments, ensuring that critical components receive more attention [8]. According to Tab. 4, TBI is cost-effective, requires fewer personnel, and extends equipment life, offering 12–18% savings over reactive maintenance. However, it may still lead to failures, includes unnecessary maintenance, and can be labor-intensive. RBI, on the other hand, reduces downtime, enhances safety, and lowers parts and labor costs, providing 8–12% savings over TBI. Its downsides are higher upfront investments in equipment and training, with benefits not always clear to management. TBI emphasizes simplicity and cost control, while RBI aims for efficiency and safety at a higher initial cost.

Case Study

ASTs data sets overview

This study analyzed 27 ASTs across various regions of Kazakhstan using RBI assessments and NIMA IM software. A detailed evaluation was carried out for each tank, with “Tank X” used as a representative example in Tab. 5. The assessment included key parameters to determine structural integrity, risk level, and overall condition within the RBI framework.Corrosion data – such as rates, repair thresholds, RWT (before/after repair), and corrosion allowances – were collected. Remaining Life (RL) and Minimum Inspection Intervals (MII) were calculated using ROSEN methodology, factoring in internal/external corrosion rates and regional climate influences.

All data were processed in NIMA IM for degradation analysis and life prediction. To support RBI implementation, input data were divided into two tables: one for fixed design/operational parameters, and another for variable corrosion-related data, allowing a clear and systematic evaluation of tank conditions and inspection priorities.

Table 5. Summary table for Tank X

Category	Parameter	Value
General Details	Tank Type	EFRT
	Product Stored	Crude Oil
	Tank Diameter	20.9 m
	Tank Height	14.9 m
	Year of Construction (Tank/Bottom)	2004
	Last Inspection Date	2024
	Intended Next Service Period	8 years
	Pump-in/Pump-out Rate	2040 m³/hr
	Storage Temperature	60°C
	Annular Present	Yes
Bottom Details	Annular Thickness	7 mm
	Bottom Thickness	5 mm
	Weld Type	Lap
	Internal Bottom Lining	Yes
	CP System Installed	Yes
	Sacrificial Anodes Installed	No
Shell Details	Thickness Course 1 to 6	6–10 mm
	Wind Stiffener Installed	No
	Anchorage	No

Tab. 6 presents constant parameters common to all ASTs, including design features, inspection confidence levels, internal lining, cathodic protection, fluid characteristics, and product price. These serve as a consistent baseline for corrosion risk evaluation. Tab. 7 contains variable data for each tank, such as measured corrosion rates (soil-side, product-side, and combined), wall thickness, inspection and installation dates, storage temperature, and potential production loss costs. This information forms the basis for estimating degradation, remaining life, and identifying high-risk tanks.

Despite identical operational conditions across all ASTs – such as crude oil storage, internal lining, cathodic protection, and temperature – corrosion rates vary, driven by local factors like soil chemistry, microbial activity, and material inconsistencies.

Table 6. Constant Data

No.	RBI Assessment Date	Internal Lining Presence	Cathodic Protection System	Fluid Condition	Inspection Data Confidence	Inspection Effectiveness	Soil Resistivity	Steam Heating Coil	Tank Storage Product	Product Price [$/barrel]
1	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
2	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
3	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
4	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
5	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
6	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
7	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
8	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
9	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75
10	05-Mar-2025	Yes	Yes	Wet	Medium	Medium	Medium	No	Crude Oil	75

Table 7. Corrosion and Operational Data

No.	Corrosion Rate – Soil Side [mm/year]	Combined Corrosion Rate [mm/year]	Corrosion Rate – Product Side [mm/year]	Last Inspection Date	Installation Date	Nominal Wall Thickness [mm]	Storage Temperature [°C]	Cost of Lost Production [$/day]
1	0.081	0.162	0.081	-	-	5.0	60	20,000
2	0.075	0.156	0.081	-	-	5.0	60	18,000
3	0.086	0.172	0.086	-	-	5.0	60	22,000
4	0.079	0.158	0.079	-	-	5.0	60	19,000
5	0.090	0.178	0.088	-	-	5.0	60	21,000
6	0.082	0.167	0.085	-	-	5.0	60	19,500
7	0.088	0.171	0.083	-	-	5.0	60	20,500
8	0.084	0.165	0.081	-	-	5.0	60	20,000
9	0.091	0.181	0.090	-	-	5.0	60	22,500
10	0.080	0.160	0.080	-	-	5.0	60	20,000

The highest combined corrosion rate recorded is 0.181 mm/year, signaling a more aggressive local environment. Given a nominal wall thickness of 5 mm, this indicates faster structural degradation and reduced service life. Production loss costs also vary, reaching up to $22,500/day, making it critical to prioritize tanks with both high corrosion and economic impact in RBI planning. These corrosion rates support tank prioritization for inspection or repair, enable predictive remaining life modeling, and guide proactive maintenance.

Fig. 4 consolidates soil-side (pink), product-side (blue), and combined (purple) corrosion rates to visually compare degradation patterns across tanks. Soil-side corrosion reflects external factors like moisture, soil chemistry, and microbial activity. Higher rates suggest inadequate cathodic protection or low soil resistivity. Product-side corrosion varies more widely, affected by stored media, lining condition, and temperature. Tanks with high internal degradation require closer inspection and potential relining.

Combined corrosion rates offer a holistic view of degradation. Tanks with high values on both sides represent critical risk and demand prioritized

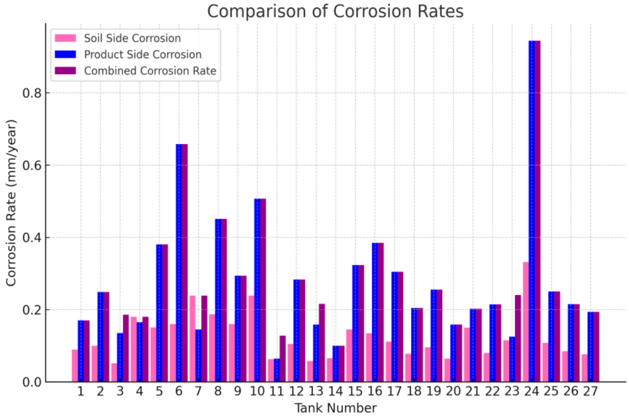


Figure 4. Comparison of Soil-Side, Product-Side, and Combined Corrosion Rates Across Storage Tanks

inspection and advanced NDT. Visualizing all three corrosion types together reveals interactions between internal and external degradation mechanisms, reinforcing the need for a risk-based rather than fixed-interval inspection approach.

Understanding these corrosion patterns supports smarter resource allocation, enhancing safety and long-term asset reliability.

Results

The risk assessment performed under the RBI methodology includes the evaluation of both PoF and CoF for 27 ASTs. Three different assessment scenarios were considered to analyze the impact of varying risk acceptance criteria on inspection planning.

Scenario 1: Risk-Based Inspection (RBI) with a PoF Target of 0.1 incidents/year

In the first scenario, a conservative RBI strategy was implemented with a PoF target of 0.1 incidents per year and a financial risk threshold of $30,000 per year. This configuration prioritizes safety and reliability, ensuring frequent inspections to mitigate the likelihood of failure.

The risk matrices in Fig. 5 and Fig. 6 show that Tank No. 19 and Tank No. 24 exceed the risk acceptance criteria due to wall loss over 50%, placing them in the high-risk zone. This necessitates urgent inspection or maintenance. The updated risk matrix for the next inspection date confirms that the proposed strategy is effective, with all tanks expected to fall within acceptable risk levels, demon-

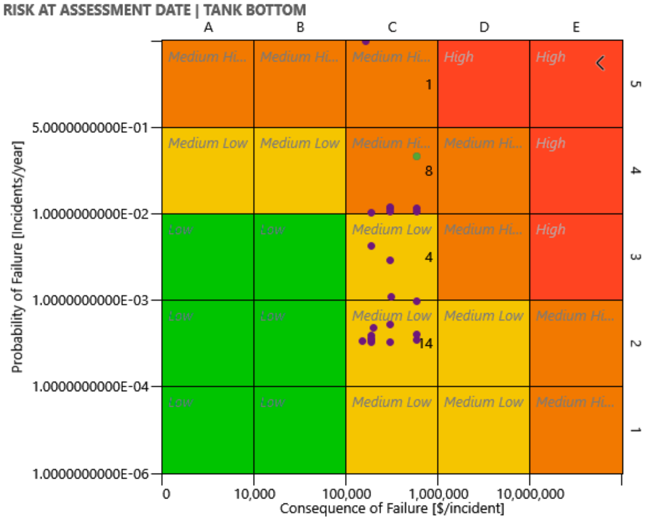


Figure 5. Risk matrix at initial inspection date showing current risk levels across tanks based on PoF and CoF

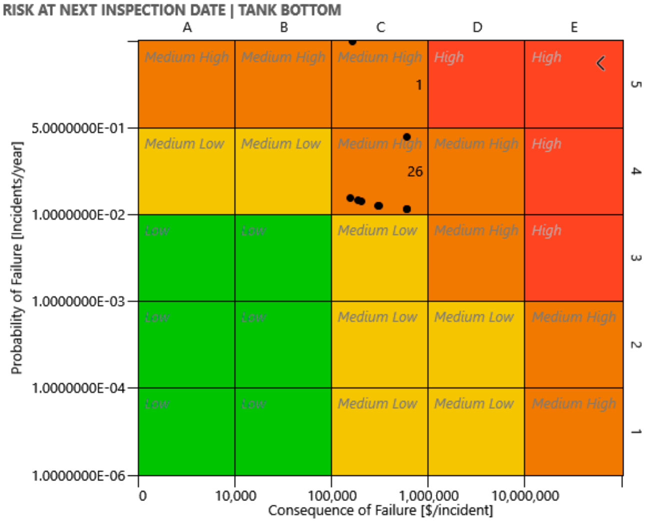


Figure 6. Risk matrix after re-inspection planning showing mitigated risk levels across all tanks

strating the value of RBI in maintaining equipment integrity and preventing failures.

The average interval between inspections in this scenario was determined to be 5.6 years, reflecting a stringent approach where failure mechanisms such as corrosion and mechanical degradation are detected at an early stage. The inspection planning chart for this scenario Fig.7 illustrates a higher frequency of scheduled inspections, particularly in earlier years.

In addition, in Fig. 8 ISO-risk plot serves as a graphical summary of risk distribution across the tank population. It clearly illustrates the correlation between PoF and financial consequences, supporting risk ranking and enabling informed decision-making in the maintenance planning process.

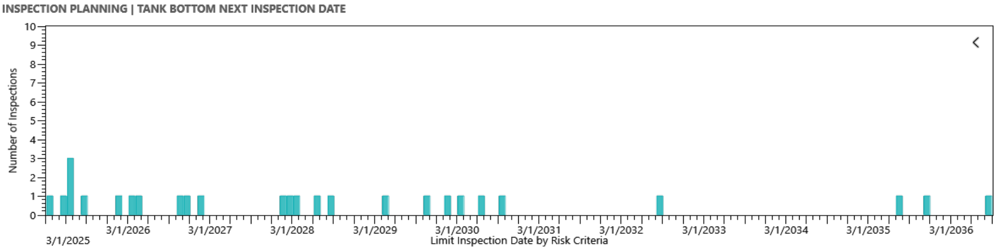


Figure 7. Inspection planning chart for Scenario 1 (PoF target: 0.1 incidents/year)

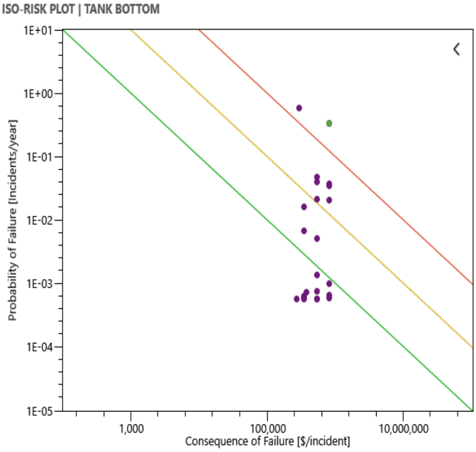


Figure 8. ISO-risk plot displaying distribution of tanks based on Probability of Failure and Financial Risk

This conservative approach minimizes operational risk by ensuring early detection of deterioration, thereby reducing the probability of severe failures. However, this comes at the cost of increased inspection and maintenance expenses, which must be weighed against the benefits of enhanced reliability and regulatory compliance.

Scenario 2: Risk-Based Inspection (RBI) with a PoF Target of 0.3 incidents/year

The second RBI scenario explores the impact of increasing the PoF target to 0.3 incidents per year and adjusting the financial risk threshold to $50,000 per year. This scenario demonstrates how adjusting risk tolerance affects inspection planning by extending inspection intervals.

With these revised parameters, the average time between inspections increased to 6.5 years, as indicated in the inspection planning chart in Fig. 9. This reduction in inspection frequency is a direct result of the increased acceptable risk level, allowing for more extended operational periods before re-inspection.

This scenario illustrates the sensitivity of inspection intervals to risk tolerance levels. By accepting a higher PoF target, the number of scheduled inspections is reduced, optimizing maintenance resources and decreasing operational disruptions. However, this approach also elevates the probability of undetected deterioration, necessitating the implementation of additional monitoring techniques, such as real-time corrosion asses-sment and predictive analytics.

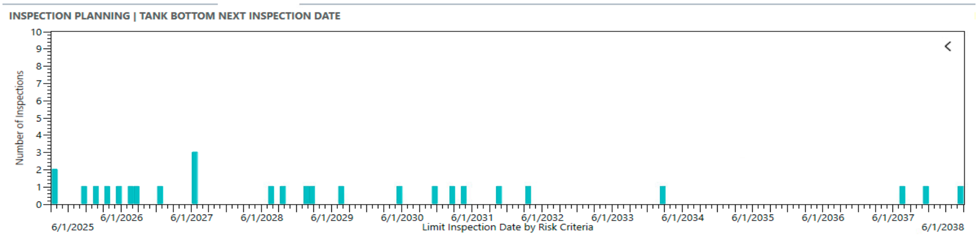


Figure 9. Inspection planning chart for Scenario 2 (PoF target: 0.3 incidents/year

Scenario 3: TBI Approach

Unlike the RBI methodologies, the TBI approach follows fixed inspection intervals, independent of actual asset condition or degradation rates. This traditional methodology assumes a uniform degradation progression, scheduling inspections at predetermined timeframes.

The limitations of TBI arise from its inflexibility and inefficiency compared to RBI strategies. Two key inefficiencies include:

1. Over-inspection: When degradation occurs at a slower rate than estimated, unnecessary inspections increase costs without a proportional risk reduction.
2. Under-inspection: When degradation is faster than anticipated, fixed intervals may lead to unplanned failures due to undetected deterioration.

While TBI remains a viable method under regulatory or operational constraints, its lack of adaptability makes it less efficient than RBI approaches. The ability to adjust inspection intervals based on evolving risk assessments, as seen in Scenarios 1 and 2, presents a more effective strategy for asset integrity management.

Risk-Based Inspection Planning and Assessment

The inspection planning results were analyzed based on the RBI methodology, considering factors such as inspection priority, scheduled inspection dates, PoF, and financial risk assessment. These factors play a crucial role in optimizing inspection intervals while ensuring asset integrity, minimizing operational risks, and reducing maintenance costs. Tab. 8 presents the results of this analysis, detailing the planned inspection schedules and associated risk metrics for the assessed aboveground storage tanks.

Tab. 8 corresponds to Scenario 1, where inspection planning is conducted using the initial RBI methodology without modifications from alternative assessment strategies. This scenario establishes a baseline approach by prioritizing inspections based on calculated risk factors, including the PoF and financial risk.

The table presents key parameters that determine inspection scheduling. The inspection priority indicates the urgency of each inspection, ensuring that higher-risk tanks are assessed first. The next and last inspection dates provide a structured timeline for evaluating maintenance history and ensuring regulatory compliance. The installation date helps assess the long-term degradation of each tank.

The PoF, expressed in incidents per year, ranges from 0.04 to 0.1, indicating varying levels of structural risk. Tanks with higher PoF values

Table 8. Inspection planning results

Tank No.	Inspection Priority	Installation Year	Next Inspection Date	Last Inspection Date	Inspection Interval [years]	Current POF Total [Incidents/year]	Risk of Failure [$/ year]
24	1	2011	July 14, 2023	July 29, 2022	1,0	0,038	30000
19	2	1996	January 3, 2024	June 1, 2022	1,6	0,100	29226
16	3	2002	March 16, 2025	March 10, 2022	3,1	0,038	30000
13	4	1989	May 15, 2025	October 22, 2021	3,6	0,038	30000
15	5	2011	June 10, 2025	October 8, 2021	3,7	0,057	30000
22	6	2000	August 30, 2025	October 10, 2022	2,9	0,057	30000
21	7	1994	January 11, 2026	December 2, 2022	3,2	0,038	30000
8	8	2013	March 29, 2026	August 31, 2024	1,6	0,057	30000
25	9	2004	April 1, 2026	December 17, 2022	3,3	0,057	30000
17	10	2011	October 18, 2026	April 1, 2022	4,6	0,056	30000
12	11	2003	November 23, 2026	November 17, 2023	3,1	0,087	30000
6	12	2013	January 7, 2027	September 30, 2024	2,3	0,056	30000
5	13	2005	January 7, 2028	August 8, 2024	3,5	0,087	30000
26	14	2003	February 8, 2028	December 28, 2024	3,2	0,081	30000
27	15	1996	March 12, 2028	January 8, 2024	4,2	0,038	30000
10	16	2013	June 10, 2028	June 22, 2024	4,0	0,057	30000
18	17	2000	August 4, 2028	March 18, 2022	6,5	0,087	30000
20	18	1983	April 24, 2029	May 2, 2022	7,1	0,056	30000
14	19	1991	October 29, 2029	November 4, 2021	8,1	0,038	30000
9	20	2013	January 8, 2030	October 25, 2024	5,3	0,057	30000
7	21	2013	March 27, 2030	December 10, 2024	5,4	0,057	30000
2	22	2004	June 3, 2030	October 15, 2024	5,7	0,087	30000
11	23	1990	September 29, 2030	August 9, 2024	6,2	0,038	30000
23	24	1990	August 17, 2032	March 23, 2022	10,6	0,087	30000
1	25	2004	July 8, 2035	August 4, 2024	11,1	0,100	26578
3	26	2005	November 9, 2035	July 4, 2024	11,5	0,087	30000
4	27	1990	August 22, 2036	July 15, 2024	12,3	0,087	30000

require closer monitoring to reduce the likelihood of failure. The financial risk of failure, measured in dollars per year, ranges from $26,577 to $30,000, emphasizing the economic impact of unplanned failures and the importance of timely inspections.

By applying this structured RBI methodology, Scenario 1 provides a data-driven framework for optimizing inspection intervals, enhancing asset reliability, and minimizing maintenance costs.

Conclusion

This study highlights the effectiveness of RBI combined with advanced tank bottom scanning technologies in optimizing re-inspection intervals for ASTs in Kazakhstan. Compared to traditional TBI, RBI offers a more systematic and data-driven approach, improving safety, reducing maintenance costs, and allowing better resource allocation. The integration of NDT methods like TBIT enables early detection of corrosion and structural issues, enhancing inspection accuracy.

However, implementation challenges remain. Kazakhstan's regulations are still largely prescriptive, requiring fixed-interval inspections and lacking probabilistic risk assessment integration. Limited industry awareness, insufficient training, and high investment costs in advanced technologies also hinder broader adoption. To enable a successful transition, regulatory updates, standardized risk thresholds, and workforce training are essential.

Future research should expand RBI to more facilities and explore integrating AI and machine learning for enhanced predictive maintenance. By adopting risk-based strategies and modern technologies, Kazakhstan can align with global standards, improve asset integrity, and ensure long-term industrial sustainability.

ADDITIONAL INFORMATION

Funding source. This study was not supported by any external sources of funding.

Competing interests. The authors declare that they have no competing interests.

Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. The greatest contribution is distributed as follows: Zhanna Dyussenova – collection, processing, and analysis of experimental data, conducting research, detailed analysis and interpretation of results, manuscript writing; Abdugaffor Mirzoev – manuscript editing, analysis revision and review.

ДОПОЛНИТЕЛЬНО

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Вклад авторов. Все авторы подтверждают соответствие своего авторства международным критериям ICMJE (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией). Наибольший вклад распределён следующим образом: Дюсенова Ж. – сбор, обработка и анализ экспериментальных данных, проведение исследования, детальный анализ и интерпретация результатов, написание рукописи; Мирзоев А. – редактирование рукописи, вычитка и проверка выполненного анализа.

REFERENCES

1. inspectioneering.com [Internet]. Inspectioneering Journal. API RP 581 Risk-Based Inspection Technology: Summary of Changes in the Newly Released Fourth Edition [cited 11 Feb 2025]. Available from: inspectioneering.com/journal/2025-02-27/11449/api-rp-581-risk-based-inspection-technology-summary-of-changes-in-the-newly-rel.
2. inspectioneering.com [Internet]. Inspectioneering Journal. Overview of API RP 581 - Risk Based Inspection Technology [cited 12 Feb 2025]. Available from: inspectioneering.com/tag/api+rp+581.
3. Al-Mitin AW, Sardesai V, Al-Harbi B, et al. Risk Based Inspection (RBI) of Aboveground Storage Tanks to Improve Asset Integrity. International Petroleum Technology Conference; 2011 Nov 15–17; Bangkok, Thailand. Available from: onepetro.org/IPTCONF/proceedings-abstract/11IPTC/All-11IPTC/IPTC-14434-MS/152650.
4. oecd.org [Internet]. OECD. Risk Governance Scan of Kazakhstan [cited 03 Mar 2025]. Available from: oecd.org/en/publications/risk-governance-scan-of-kazakhstan_cb82cae9-en.html.
5. hghouston.com [Internet]. The Hendrix Group Inc. The Hendrix Group [cited 03 Mar 2025]. Available from: hghouston.com/risk-based-inspection.
6. rosen-group.com [Internet]. Rosen Group. Asset Integrity Management and Data Management Software [cited 05 Mar 2025]. Available from: rosen-group.com/en/expertise/product-and-service-finder/nima.
7. Reynolds JT. Risk Based Inspection - Where Are We Today? CORROSION 2000; 2000 Mar 26–31; Orlando, Florida, USA. Available from: onepetro.org/NACECORR/proceedings-abstract/CORR00/CORR00/NACE-00690/111761.
8. petrosync.com [Internet]. PETROSYNC. Risk-Based Inspection as Industrial Disaster Prevention [cited 20 Mar 2025]. Available from: petrosync.com/blog/risk-based-inspection-application-in-industry/.

СПИСОК ИСПОЛЬЗОВАННОЙ ЛИТЕРАТУРЫ

1. inspectioneering.com [интернет]. Inspectioneering Journal. API RP 581 Risk-Based Inspection Technology: Summary of Changes in the Newly Released Fourth Edition [дата обращения 11.02.2025]. Доступ по ссылке: inspectioneering.com/journal/2025-02-27/11449/api-rp-581-risk-based-inspection-technology-summary-of-changes-in-the-newly-rel.

2. inspectioneering.com [интернет]. Inspectioneering Journal. Overview of API RP 581 - Risk Based Inspection Technology [дата обращения 12.02.2025]. Доступ по ссылке: inspectioneering.com/tag/api+rp+581.
3. *Al-Mitin A.W., Sardesai V., Al-Harbi B., et al.* Risk Based Inspection (RBI) of Aboveground Storage Tanks to Improve Asset Integrity // International Petroleum Technology Conference; November 15–17, 2011; Bangkok, Thailand. Доступ по ссылке: onepetro.org/IPTCONF/proceedings-abstract/11IPTC/All-11IPTC/IPTC-14434-MS/152650.
4. oecd.org [интернет]. OECD. Risk Governance Scan of Kazakhstan [дата обращения 03.03.2025]. Доступ по ссылке: oecd.org/en/publications/risk-governance-scan-of-kazakhstan_cb82cae9-en.html.
5. hghouston.com [интернет]. The Hendrix Group Inc. The Hendrix Group [дата обращения 03.03.2025]. Доступ по ссылке: hghouston.com/risk-based-inspection.
6. rosen-group.com [интернет]. Rosen Group. Asset Integrity Management and Data Management Software [дата обращения 05.03.2025]. Доступ по ссылке: rosen-group.com/en/expertise/product-and-service-finder/nima.
7. *Reynolds J.T.* Risk Based Inspection - Where Are We Today? // CORROSION 2000; March 26–31, 2000; Orlando, Florida, USA. Available from: onepetro.org/NACECORR/proceedings-abstract/CORR00/CORR00/NACE-00690/111761.
8. petrosync.com [интернет]. PETROSYNC. Risk-Based Inspection as Industrial Disaster Prevention [дата обращения 20.03.2025]. Доступ по ссылке: petrosync.com/blog/risk-based-inspection-application-in-industry/.

AUTHORS' INFO

***Zhanna Ualiyeva**
ORCID 0009-0004-7703-5145
e-mail: *jannadyussenova0@gmail.com.*
Abdugaffor Mirzoev
ORCID 0009-0009-9416-8974
e-mail: *gmirzoev@rosen-group.com*.

ИНФОРМАЦИЯ ОБ АВТОРАХ

***Жанна Уалиева**
ORCID 0009-0004-7703-5145
e-mail: *jannadyussenova0@gmail.com.*
Адбугаффор Мирзоев
ORCID 0009-0009-9416-8974
e-mail: *gmirzoev@rosen-group.com*.

*Автор, ответственный за переписку / Corresponding Author