JOINT STOCK COMPANY

«SAFETY SYSTEMS AND TECHNOLOGIES. TEKHDIAGNOSTICA»

Specialised Centre for Diagnosing of Process Equipment of Oil and Gas Fields with High H_2S Content and Gas Processing Plants of JSC Gazprom

PROCESS EQUIPMENT SAFETY MANAGEMENT SYSTEM AND TECHNIQUES BASED ON FAILURE RISK CRITERIA

(ACCORDING OF THE TECHNOLOGIC REGULATION LAW REQUIREMENTS)

FOR GAS AND CONDENSATE PROCESSING PLANTS AND OIL REFINERIES WITH HIGH H_2S CONTENT

BOOKLET OF TECHNOLOGIC ACHIEVEMENTS IN COMMEMORATION OF THE 15^{TH} ANNIVERSARY OF THE COMPANY

CONCLUSION
on “Process Equipment Safety Management System and Techniques based on Failure Risk Criteria”

Comprehensive measures of management, maintenance and enhancement of safety not only of the most critical components of process equipment, but also of all gas-processing and chemical installations of oil and gas industry are considered as one of the highest priorities of ensuring reliability and assessing the efficiency of process equipment performances as provided for by the Federal Laws on Technological Regulation and on Safety of Hazardous Industrial Facilities. Definite quantitative risk parameters, which help disclose areas of potential failures, accidents and calamities, as well as their consequences and resulting damages are the most important safety indicators. In recent decades, research on theoretical and practical safety- and risk-related issues has become the subject matter of federal target-oriented, industrial and regional scientific and technological programmes. Many key academic, scientific and research organisation of Russia, industry-oriented scientific, design and technological institutes, higher education establishments and specialised centres are taking part in its implementation.

Gas processing and chemical treatment installations used for production, transportation and processing of H_2S***-bearing gases and condensate are characterised by enhanced complexity of safety and risk analyses carried out on this equipment. This fact results from the combination of multiple factors such as mechanical, thermal, corrosive, erosive, vibration, seismic, aerohydrodynamic processes and damages of load-bearing elements, as well as from hazardous impacts of process medium on human beings and the environment.***

Russia’s Specialised Centre for Diagnosing of Process Equipment of Oil and Gas Fields with High H_2S ***Content and Gas Processing Plants of JSC Gazprom - JSC Tekhdiagnostica. Safety Management Systems and Techniques – conducts the most comprehensive and fundamental study of the above problems in order to design and build process equipment to be operated in close contact with*** H_2S***-bearing gases and condensate. This booklet contains integrating scientific and operational data, giving an idea of the complexity of the problem of safety and risk assessment with regard to such specific operational factor as the presence of*** H_2S ***in the process.***

Scientific research and application development of JSC Tekhdiagnostica in creative cooperation with parent organisations of Gazprom, Rostechnadzor, with academic and higher education establishments, with designers of diagnosing systems make it possible to establish a unified safety management and analysis systems based on failure risk criteria with varying gravity of consequences. The booklet’s format is based on a fairly clear logical principle – it describes actual problem, main failure factors, structure of safety analysis techniques, risks and failures classification principles, dimensional model of risks, step-by-step measures to control probability of failures at various operational stages. On the booklet’s pages one can find illustrative and informative diagrams, description of methods and techniques, and equations and models of failure risk analyses applied while implementing the national policy in the field of technological regulation to ensure industrial safety and prevention of emergency situations.

The undeniable importance of the given level of technical diagnosing, determination of basic parameters such as strength, service life and risks with plotting a summary matrix graphs of risk levels becomes evident while taking justified decisions to continue operation of process equipment within and outside the specified lifetime limits, to carry out repair and recovery operations or to suspend production.

Pages of the booklet dedicated to scientific methods and techniques contain data on guidelines and regulatory norms and standard of JSC Tekhdiagnostica, supplies of test equipment and instruments to check for technical conditions of process equipment, and on design justification of serviceability limit conditions.

In future, JSC Tekhdiagnostica intends to further develop such themes as risk criteria database expansion (individual, social and economical risks of failures, accidents and disasters), introduction to the analysis of design, beyond design and hypothetical basis accidents, methods and techniques of protection of gas and chemical treatment installations depending on risk levels and classification, creation of integrated systems of monitoring of in-field equipment and automatic protective systems. Information presented in the booklet can be used as a database for completion of these new tasks.

The booklet will not only be useful for a wide range of specialists working in the specific area of strength, service life and risk analysis of the process equipment which operates in the environment with a high H_2S content, but also for people working in other sectors of oil, gas and chemical industries, power generation industry, pipeline construction, and metallurgy. This will help develop new ways of technological regulation, based on the fulfilment of standard governmental requirements for provision and enhancement of integrated safety with the use of unified risk criteria for the population, technosphere and ecological environment.

June 16, 2006 Corresponding Member of Sciences Academy of Russia’s N.A. Makhutov

I. The actuality of development and utilisation of the system is associated with changes in the Government's attitude to safe operating of industrial installations with regard to the degree of risk of inflicting damages (see Figure 1a) and depends on the considerable growth of actual and forecasted indices of production induced emergencies at Gas Processing and Chemical treatment Plants (GPCP) and installations in oil and gas industry by RD 03-418 criteria (see Figure 1b)

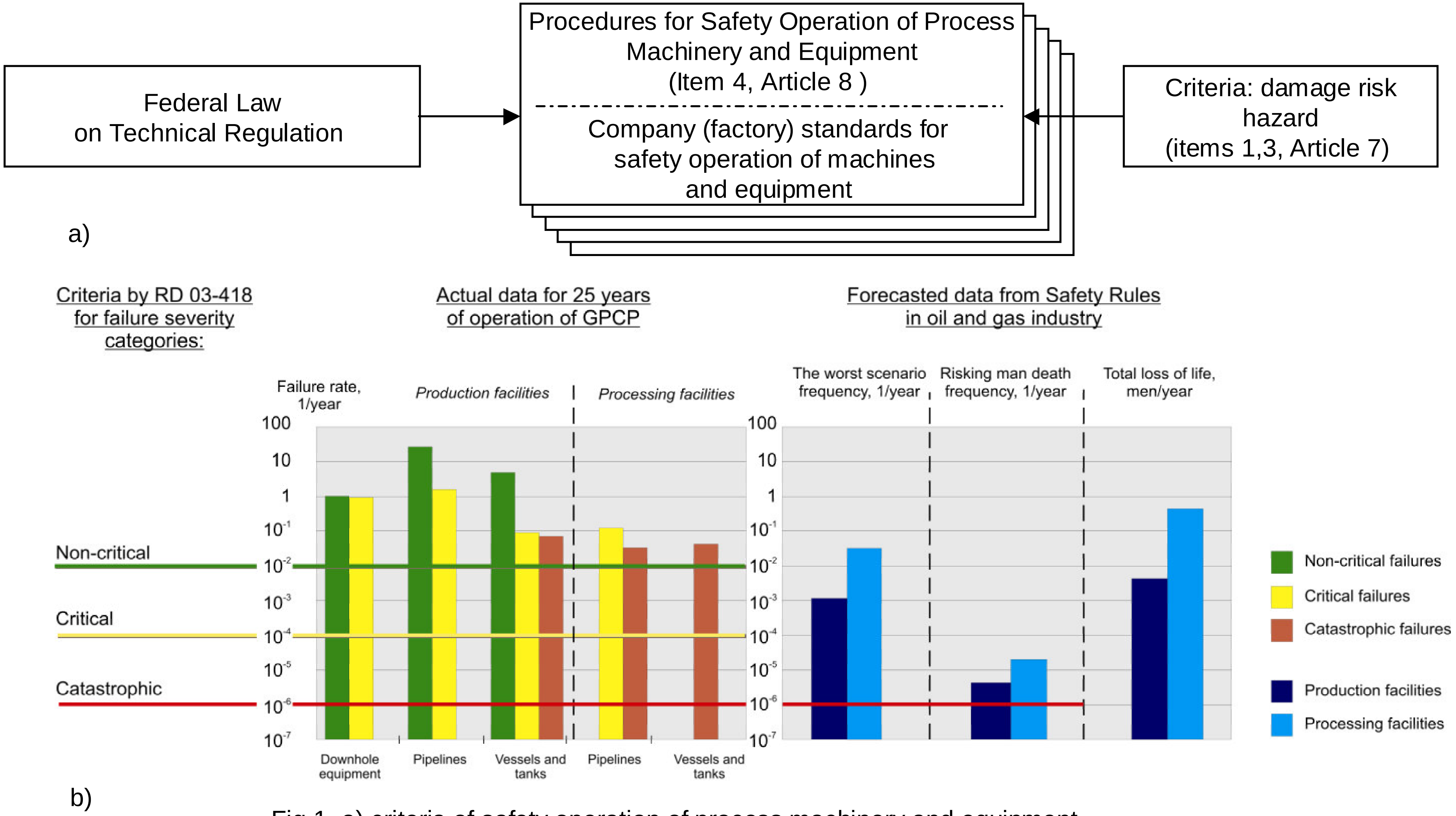


Fig.1 a) criteria of safety operation of process machinery and equipment
b) actual and forecasted indices of production induced emergencies at gas processing and chemical treatment plants and installations in oil and gas industry

II. The existing problem of safety management and prevention of failures, accidents and emergency situations when operating gas and oil industry process equipment exposed to H_2S environment has its specifics such as corrosive wear of walls, sulphide corrosive cracking of metal under stress and hydrogen induced cracking. At that, sulphide corrosive cracking of metal and hydrogen induced cracking cause defects which are hidden inside the wall and may lead to spontaneous failure (destruction) of equipment. An investigation of the problem of prevention of failures, accidents and emergency situations during long-term operation of the equipment exposed to H_2S medium is based on best domestic and foreign practices in view of regulations and standard requirements for design, construction, fabrication and operation of this equipment. Over 2000 causes of failures, damages and destructions of various components of process equipment of the Orenburg Gas Processing Plant for the past 25 years have been analysed starting from the very beginning of operation. Cause analyses results are shown in Figures 2 and 3.

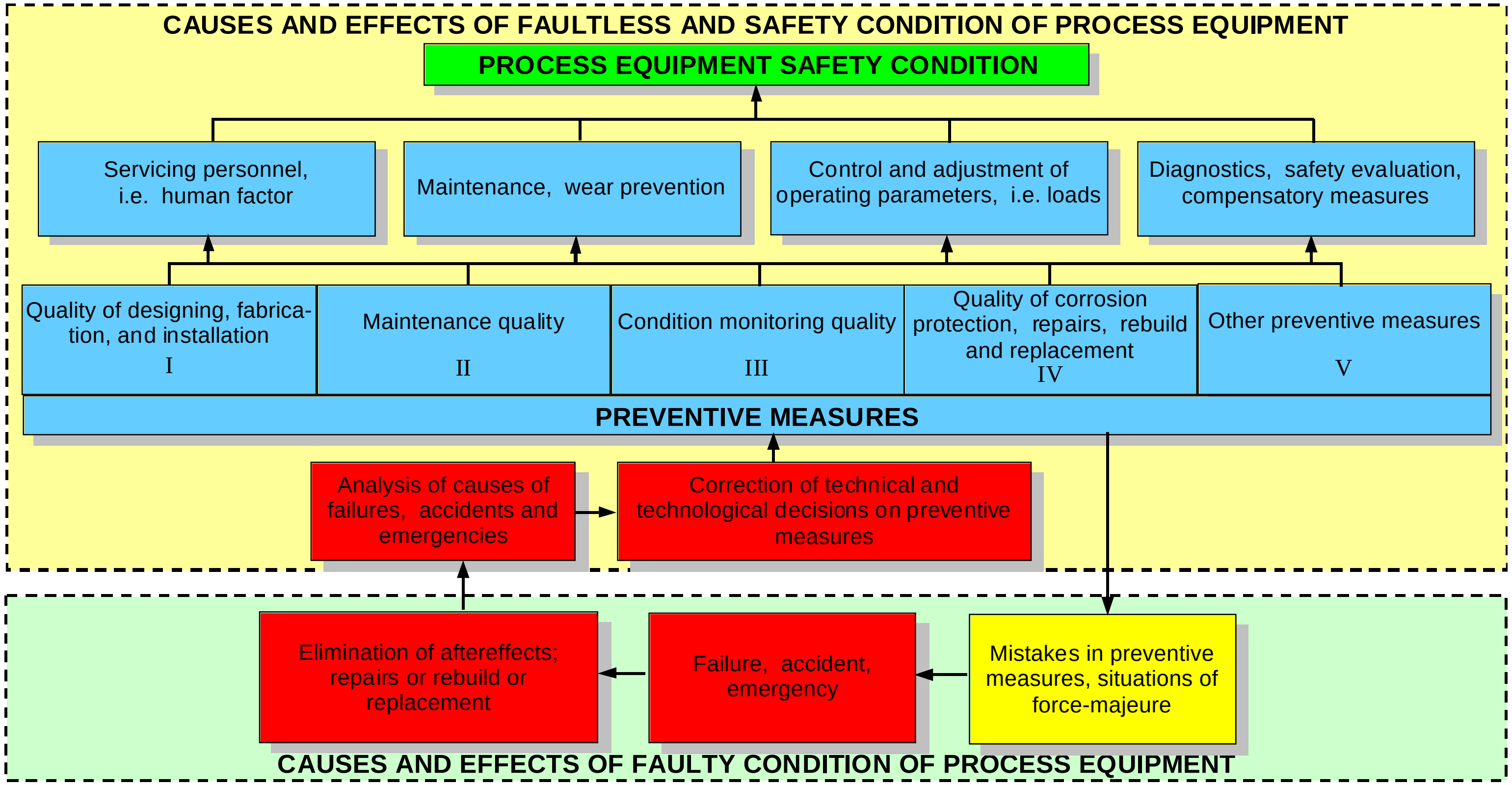


Fig.2. Cause and Effect Diagram of Serviceable and Faulty Conditions, Failures, Accidents and Emergencies as Operating Gas Processing and Chemical Facilities

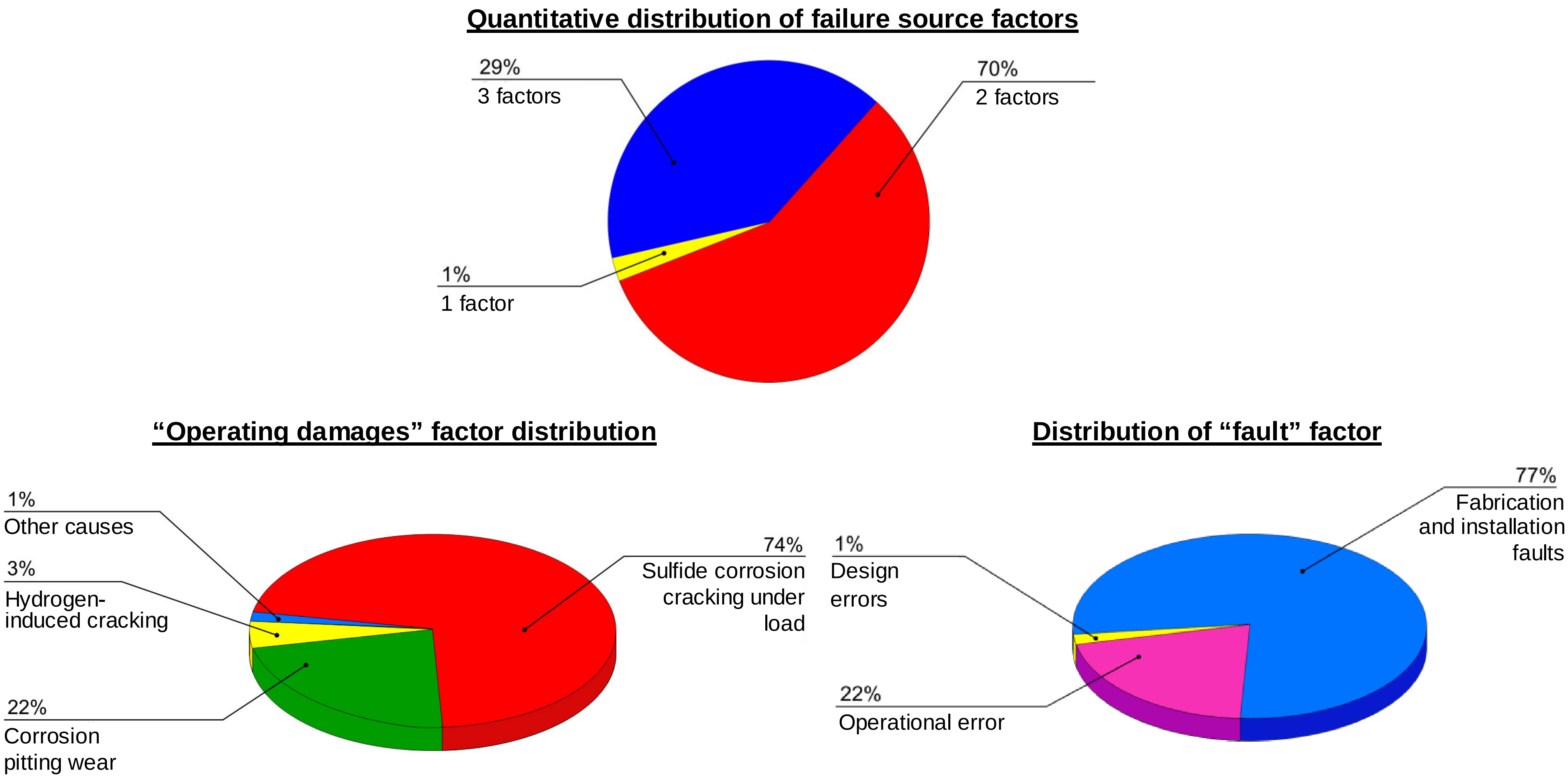


Fig.3. Distribution of Failure Sources and Collapse of Gas Processing and Chemical Treatment Equipment Components for 25 Years

The analyses results helped come to the conclusion that most of accidents and damages are caused by failures of various components of process equipment; failures and malfunctions of components of process equipment are caused by multiple systematic factors; actually in all the failures and damages occurred because of corrosive effects of the operating environment, as well as because of mistakes in designing, manufacturing, installing and operating of the equipment; failures can be prevented in case of timely, i.e. "early" detection of malfunctions and other defects in the equipment components, assessment of damaged equipment operation hazards and appropriate preventive measures to be taken.

III. On the basis of works of some prominent scientists in the field of reliability and safety of hazardous structures and results of tests and analyses performed, it has become possible to formulate and then resolve the issue of conceptualisation and development of safety management techniques and methods of prevention of failures, accidents and emergency situations when operating process equipment of gas processing and chemical plants by risk criteria and failure probability.

The root of the concept lies in the classification of all pieces of equipment of gas processing and chemical installations by safety levels – the risk of failure of various components of process equipment and the application of differentiated risk-associated corrective effects to improve safety and to monitor operating conditions. Controlling actions are being systematically planned an implemented by using well defined methods and techniques such as:

- methods, volumes and frequency of periodic monitoring and correction of operating conditions of various components of process equipment by defect detectability criteria;

- process equipment safe operation forecasting techniques by equipment component failure risk and probability criteria.

For this concept to come to life a structural diagram (block scheme) of the safety management techniques being used to operate process equipment of gas processing and chemical installations (systems) and the diagram- related model of integrated methods of monitoring of operating conditions and prevention of failures of gas processing and chemical installations have been substantiated and developed.

In addition to this, a series of technical and technological solutions have been found to ensure safety and procedural compliance of all components of the system such as:

- establish process equipment operator's (company) policy, based on state, departmental and in-house standards, requirements and other regulatory documents, which determine responsibilities, authorities, standards and procedures for safety, financing planning and execution of works, principles of accounting and many other rules and guidelines, providing for, in aggregate, the consistency of actions taken by each particular company to maintain a permissible level of operational safety and mitigation of emergencies;

- perform condition monitoring and fault prevention based on data support and analyses of methods and techniques of maintaining the required safety level of process equipment;

- carry out work quality analyses and functional efficiency reviews, and preparation of corrective measures;

- improve the system by reviewing existing criteria, standards and other regulatory documents and prepare new ones; enhance personnel qualifications; develop material and technical basis and adaptation of methods of survey and correction of operating conditions of process equipment components with regard to gas processing and chemical industry.

As indicated in Figure 4, along with other systems, the developed system is appropriately incorporated into the safety management system of hazardous installations of gas processing and chemical industry.

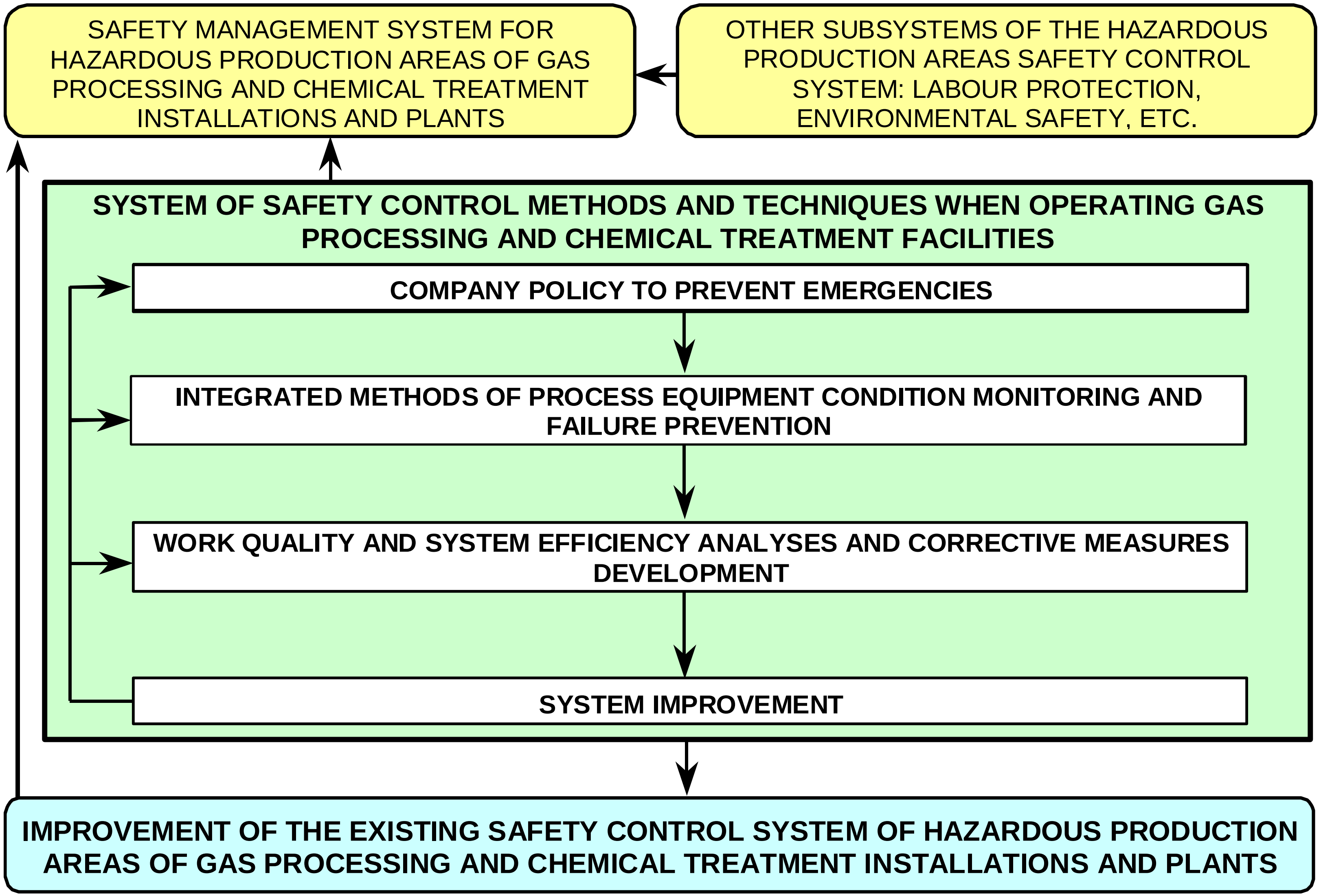


Fig.4. Schematic Diagram of Safety Management System of Gas Processing and Chemical Treatment Equipment

As indicated in Figure 5, the proposed scheme is integrated at the level of process facilities into state-owned systems of industrial safety and prevention and elimination of emergencies.

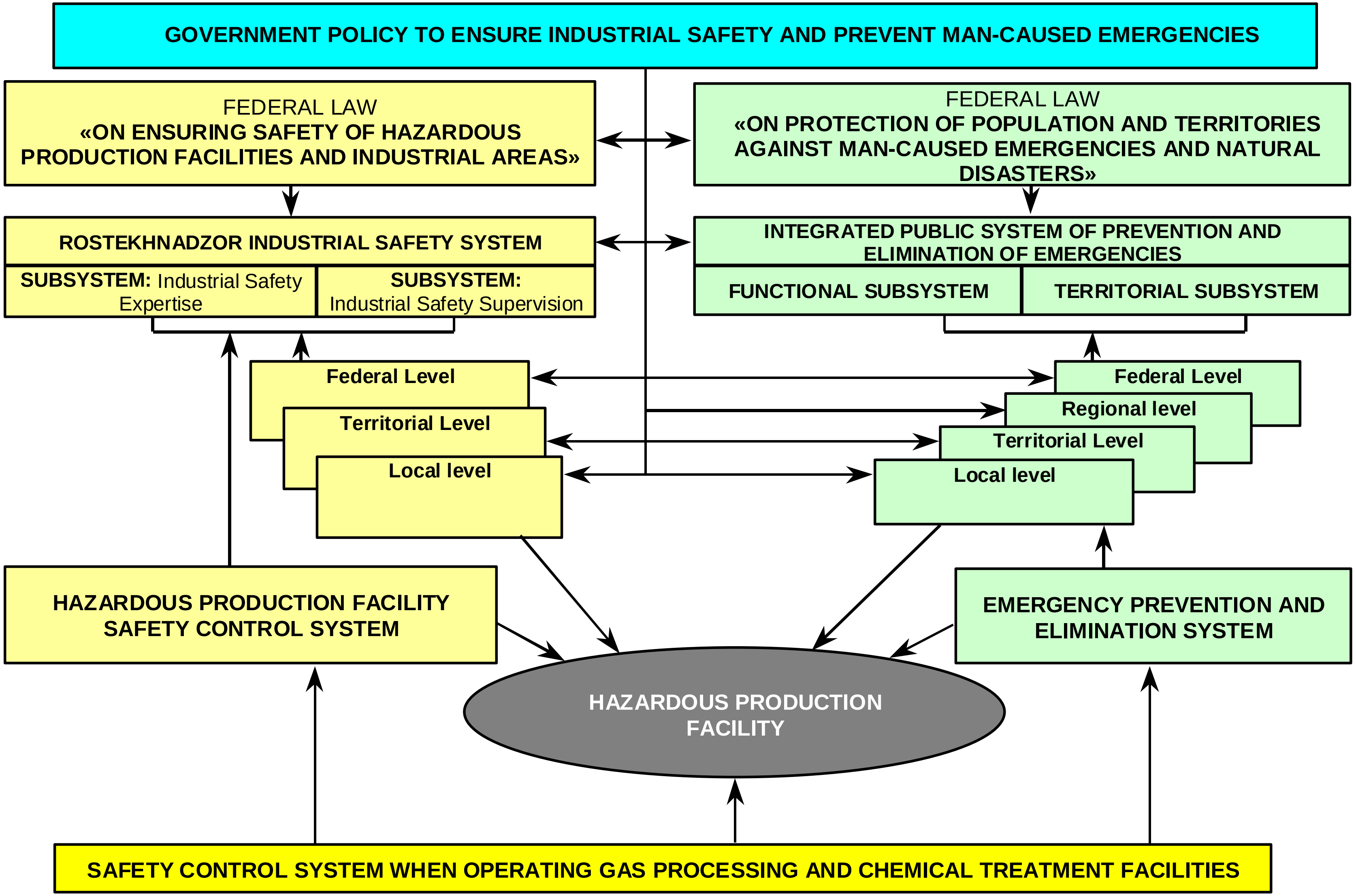


Fig.5. Proposed Integration Scheme for State Safety and Emergency Prevention Systems of Hazardous Industries

As shown in Figure 6, the proposed scheme also provides for a partial solution of issues concerning governmental assurance of industrial safety, as well as prevention and elimination of emergencies.

FEDERAL LAW

«ON PROTECTION OF POPULATION AND TERRITORIES AGAINST MAN-CAUSED EMERGENCIES AND NATURAL DISASTERS»

INTEGRATED PUBLIC SYSTEM OF PREVENTION AND ELIMINATION OF EMERGENCIES

FUNCTIONAL SUBSYSTEM	**TERRITORIAL SUBSYSTEM**

EXECUTING AUTHORITIES:
- Federal Executive Authorities;
- Russia's Ministry of Emergencies;
- Federal Centre for Monitoring and Forecasting;
- RF Regional Executive Authorities;
- Local government authorities.

OBJECTIVES:
1. Collect and process information on protection of population and territories against emergencies.
2. Prepare population to act in emergencies.
3. Public expertise, supervision and control in the field of protection of population and territories against emergencies.
4. Forecasting and assessment of social and economic consequences of emergencies.
5. Provide reserve financial and material supplies for elimination of accidents and emergencies.
6. Elimination of emergencies.
7. Social protection of victims of emergency situations.
8. **Man-caused emergency prevention.**

FEDERAL LAW

«ON ENSURING SAFETY OF HAZARDOUS PRODUCTION FACILITIES AND INDUSTRIAL AREAS»

ROSTEKHNADZOR INDUSTRIAL SAFETY SYSTEM

SUBSYSTEM: INDUSTRIAL SAFETY SUPERVISION	**SUBSYSTEM: INDUSTRIAL SAFETY EXPERTISE**

EXECUTING AUTHORITIES:
- Rostekhnadzor;
- Research Center "Industrial Safety";
- Hazardous production facility operating organizations;
- Expert organizations.

OBJECTIVES:
1. Exercise Federal control over industrial safety.
2. Exercise Federal control over industrial safety.
3. Certification of production equipment of hazardous industrial areas.
4. Inspection and verification of safety of hazardous industrial areas.
5. Registration of hazardous production areas.
6. Localization and elimination of aftereffects of accidents.
7. **Develop and apply safety control system in hazardous industrial areas.**
8. **Accident elimination and prevention.**

SYSTEM OF SAFETY CONTROL METHODS AND TECHNIQUES WHEN OPERATING GAS PROCESSING AND CHEMICAL TREATMENT FACILITIES

OBJECTIVES:
1. Monitor actual condition of process equipment and provide controlled operation of defective equipment.
2. Forecast process equipment safe operation lifetime.
3. Plan out and perform repairs or replacement of equipment by risk criteria and failure probability.
4. Improve preventive measures and provide for self-improvement of the system.

Fig.6. Objectives of the proposed scheme of implementation of state policy of safety assurance and emergency prevention and elimination in hazardous industries

The model of integrated methods and techniques of monitoring of operating condition and failure prevention measures (Safety Package) is shown in Figure 7.

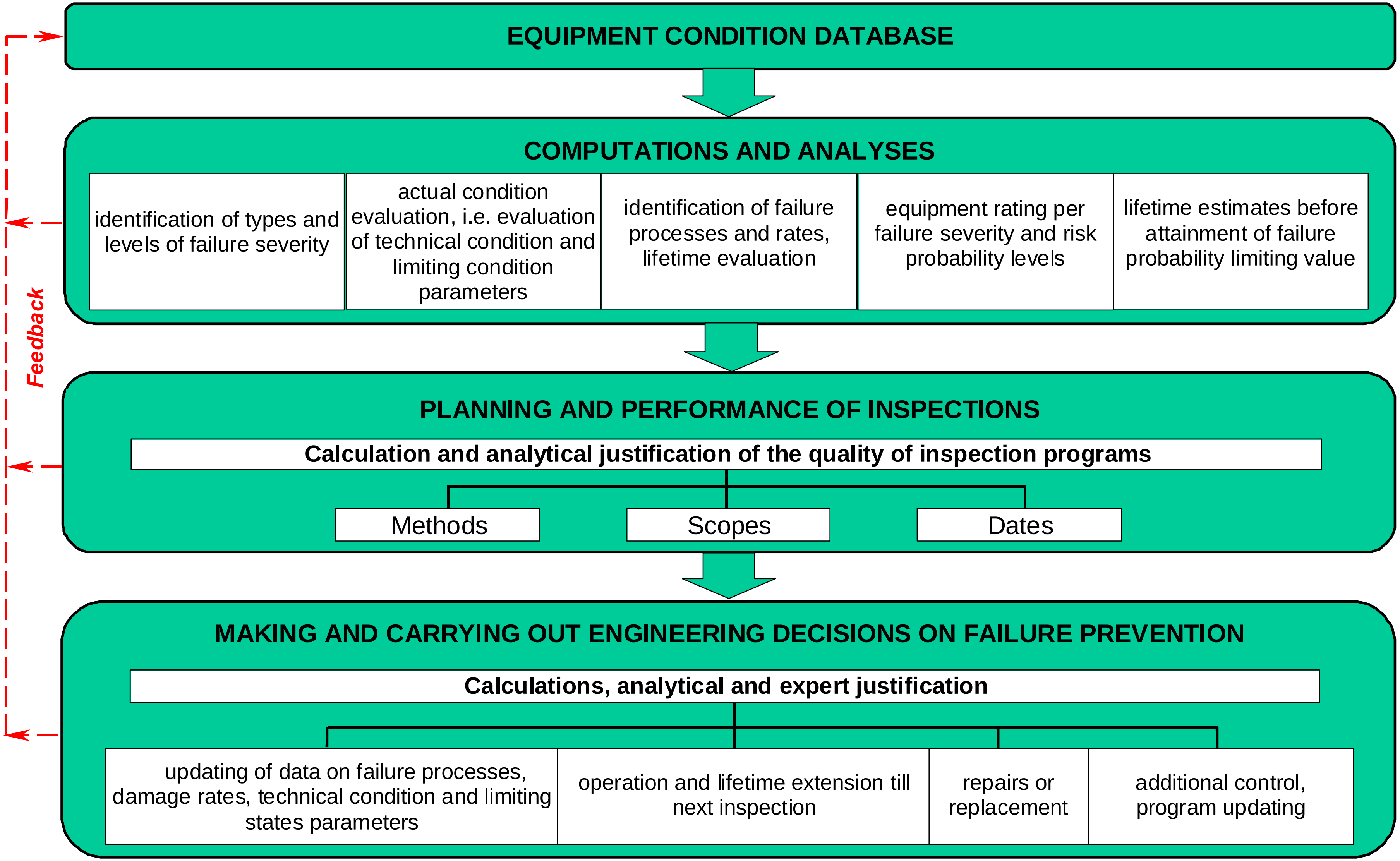
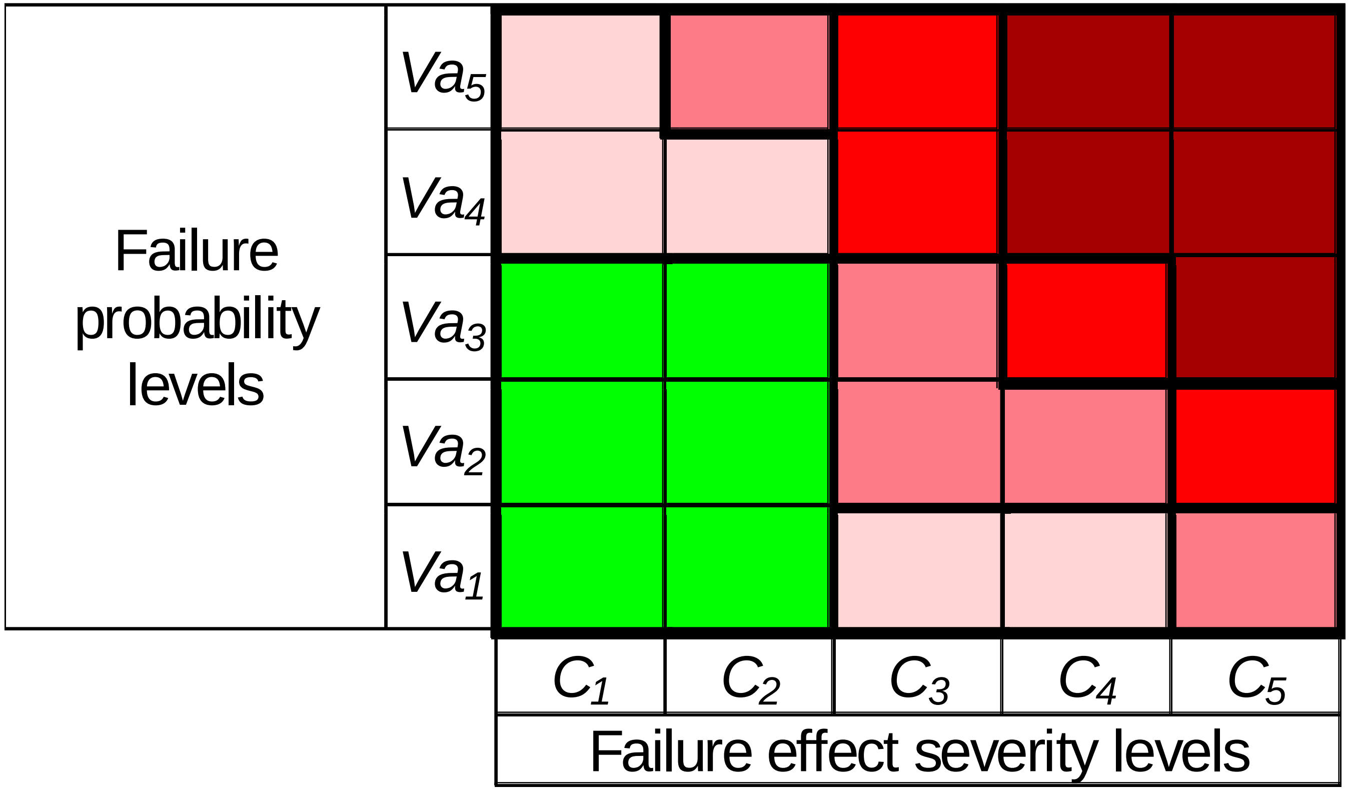


Fig.7. Model of Integrated Methods and Techniques of Monitoring of Operating Condition of Gas Processing and Chemical Treatment Equipment and Failure Prevention

The semi-quantitative analysis matrix scheme (see Figure 8) was prepared to determine the degree of failure hazard for various components of gas processing and chemical equipment ($Ra_{1...5}$); hazard degrees will be determined on the basis of probability level criteria ($Va_{1...5}$) and failure criticality ($C_{1...5}$).

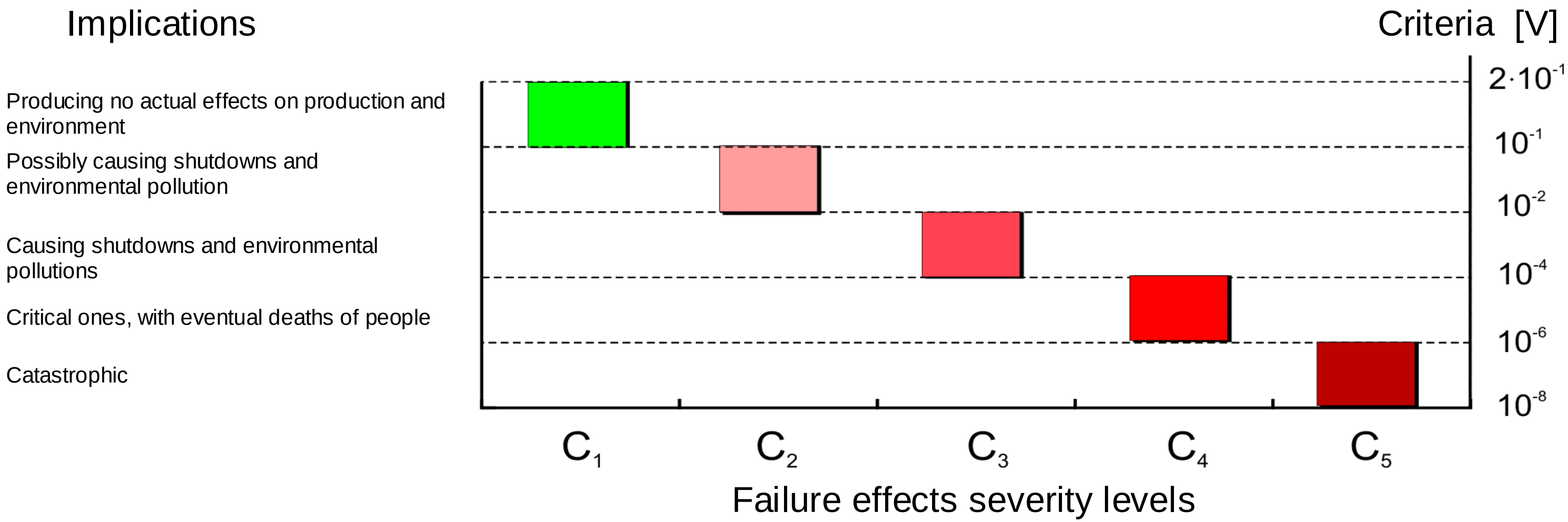


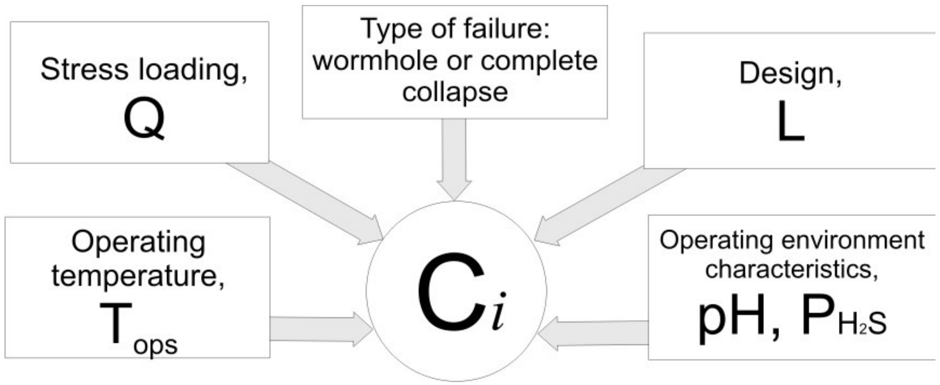
Ra_5 – high risk ; Ra_4 – risk above average ; Ra_3 – average risk ;

Ra_2 – low risk ; Ra_1 – very low risk

Fig.8. Semi-quantitative failure risk analysis matrix scheme for gas processing and chemical treatment equipment components

Levels of failure severity as consequences of possible accidents will be defined by relevant criteria which have been well-grounded during tests and analyses depending on operational characteristics of process equipment, operating environment and the type of a possible breakdown, equation (1). Limiting probability value criteria have been defined for each level of failure severity after considering the results of analyses of domestic, national and international standards (see Figure 9).

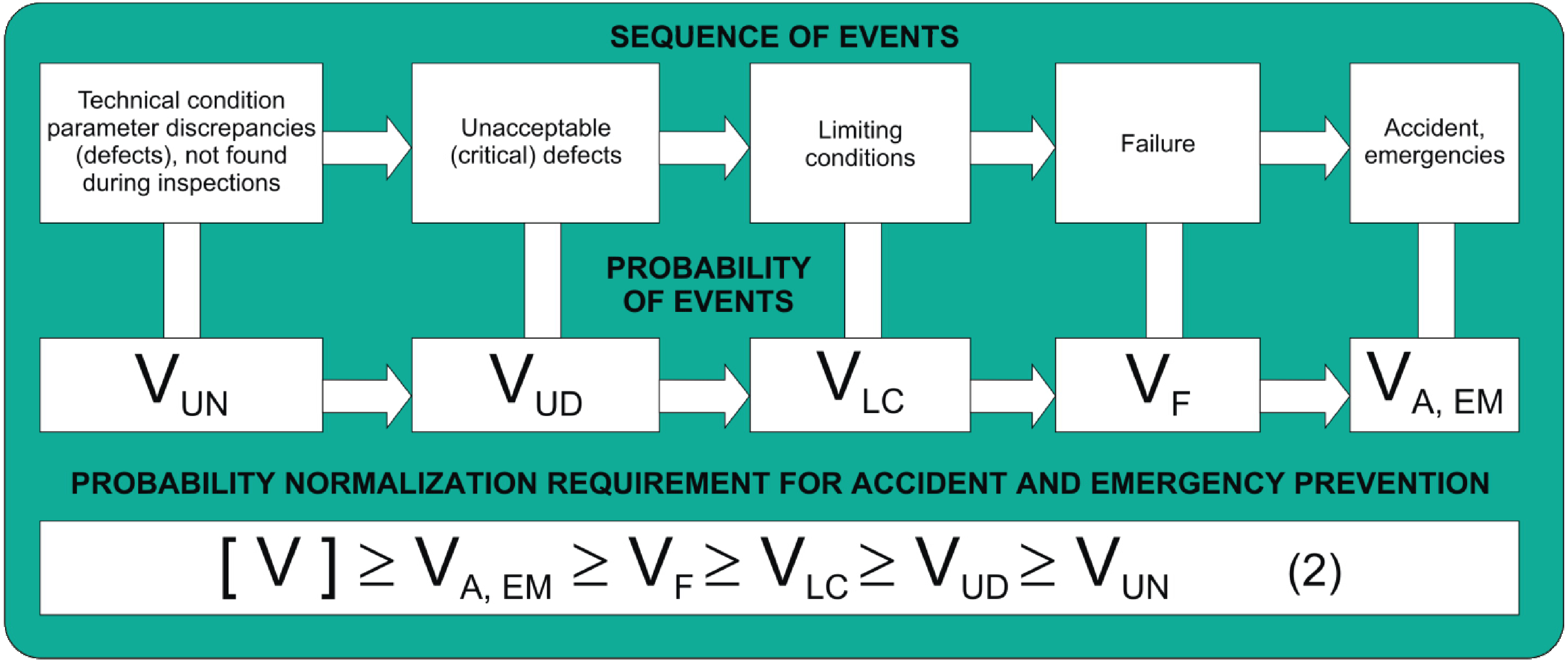




$$C_i = f(Q, T_{OPS}, L, pH, P_{H_2S}) \quad \textbf{(1)}$$

Fig.9. Failure Criticality Level Criteria and Limiting Failure Probability Values

The sequence of occurrence of undesired events causing breakdowns and failures of gas processing and chemical treatment equipment as well as conditions for valuation of permissible levels of undesired event probability during accident, emergency and failure prevention (where [V] – an acceptable value of failure against specified failure criticality category) are shown in Figure 10, equation (2)

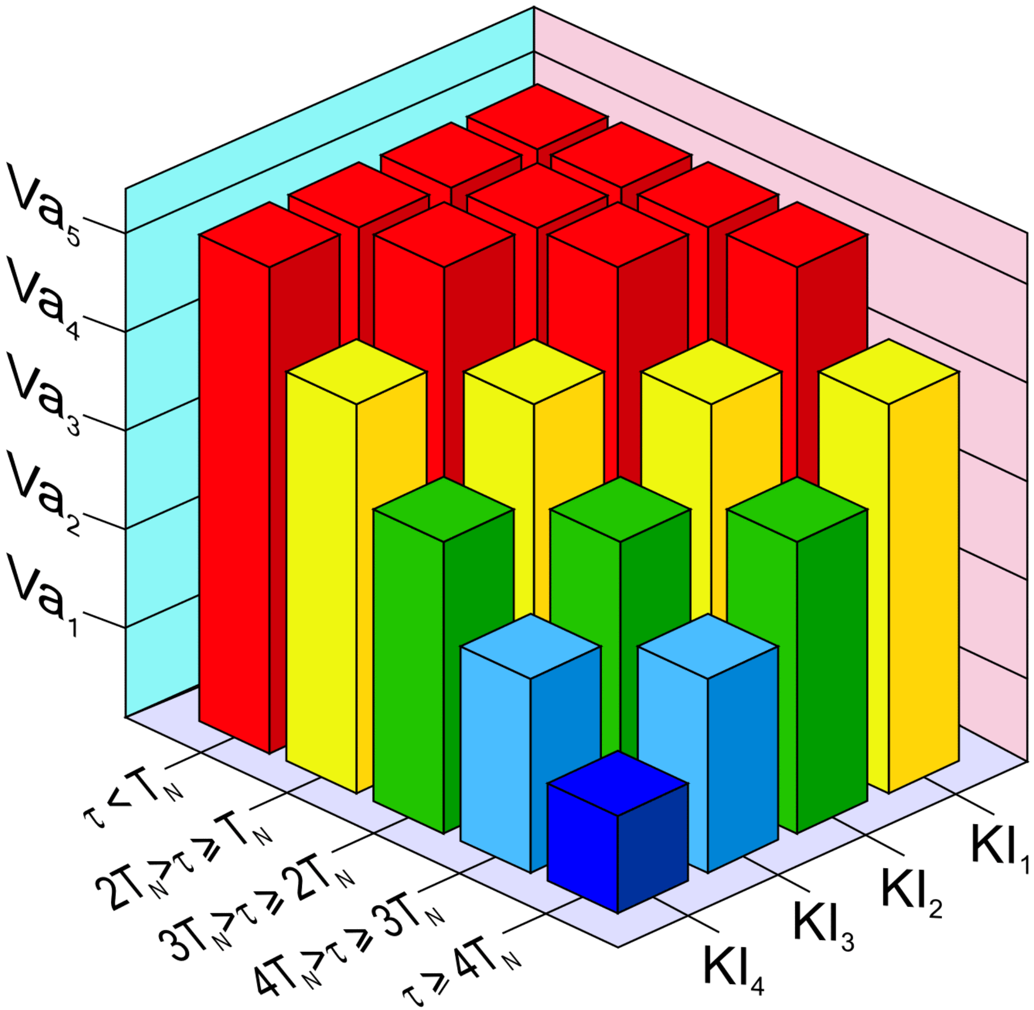


$$[V] \geq V_{A,\,EM} \geq V_{F} \geq V_{LC} \geq V_{UD} \geq V_{UN} \qquad (2)$$

Fig.10. Sequence and conditions of valuation of occurrence of undesired events causing failures and breakdowns of gas processing and chemical treatment equipment

Since accidents and emergencies are rare events, and there is no true failure statistics for each component of process equipment, the intensity and probability of occurrence of potential accidents and emergencies within the proposed system will be determined by using equipment component survey data.

The distribution of equipment components throughout failure probability levels (Figure 11) is done on the basis of established dependence, equation (3), from a forecasted residual life value till transition of equipment components into the ultimate limit condition with regard to inspection quality levels.



Va_i – ***failure probability level***

KI_i – ***inspection quality level***

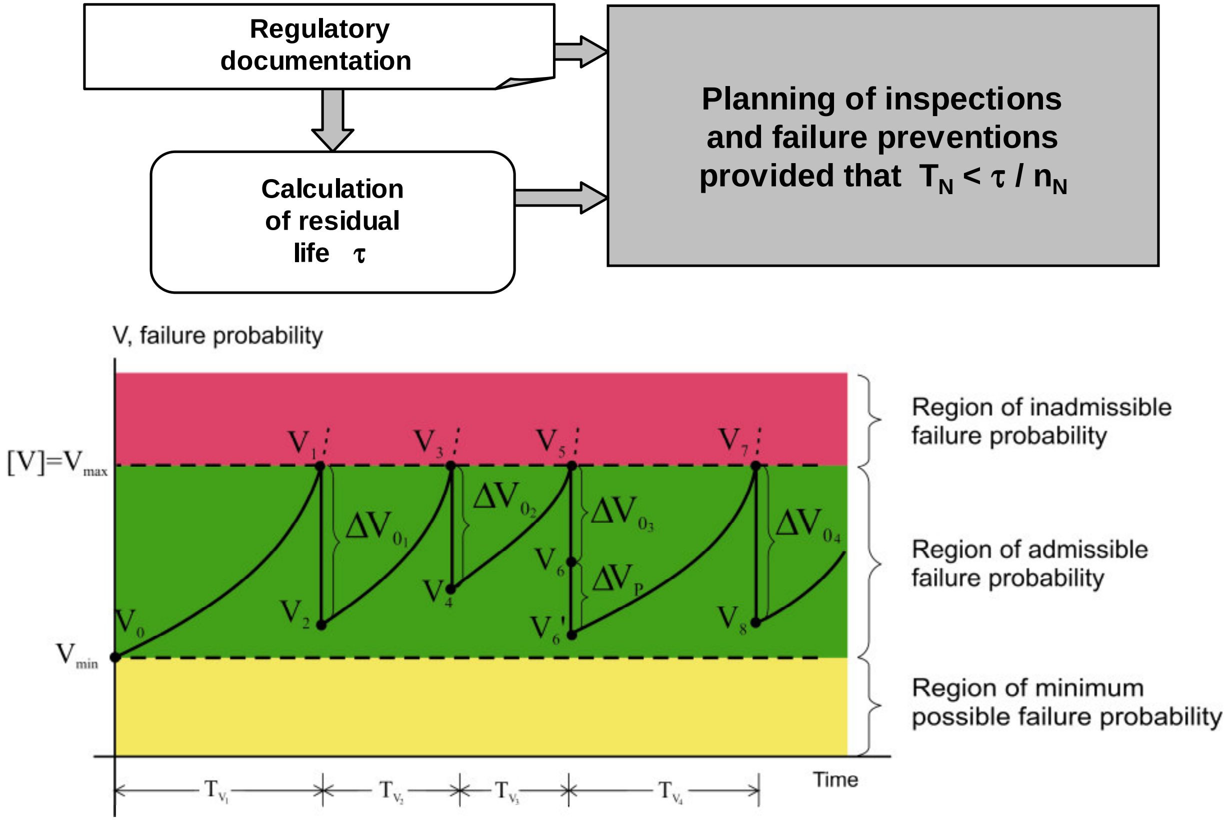
T_N – ***standard period of operation between inspections***

τ – ***residual lifetime***

$$Va_i = f(\tau, KI_i) \qquad (3)$$

Fig.11. Graphic picture of dependence of process equipment component failure probability levels on residual lifetime and quality of inspection

The planning of inspections (Figure 12) and failure preventions for equipment components assigned to the failure risk levels of Ra_1-Ra_4 is done on the basis of standard deterministic predictions of their lifetime. The planning of inspections of equipment having the failure risk level of Ra_5, and by the management's decision, of installations with the failure risk level of Ra_4, is carried out on the basis of operating life calculation results till failure probability value reaches its peaks.



Option 1: τ is calculated for components with Ra_1 - Ra_4

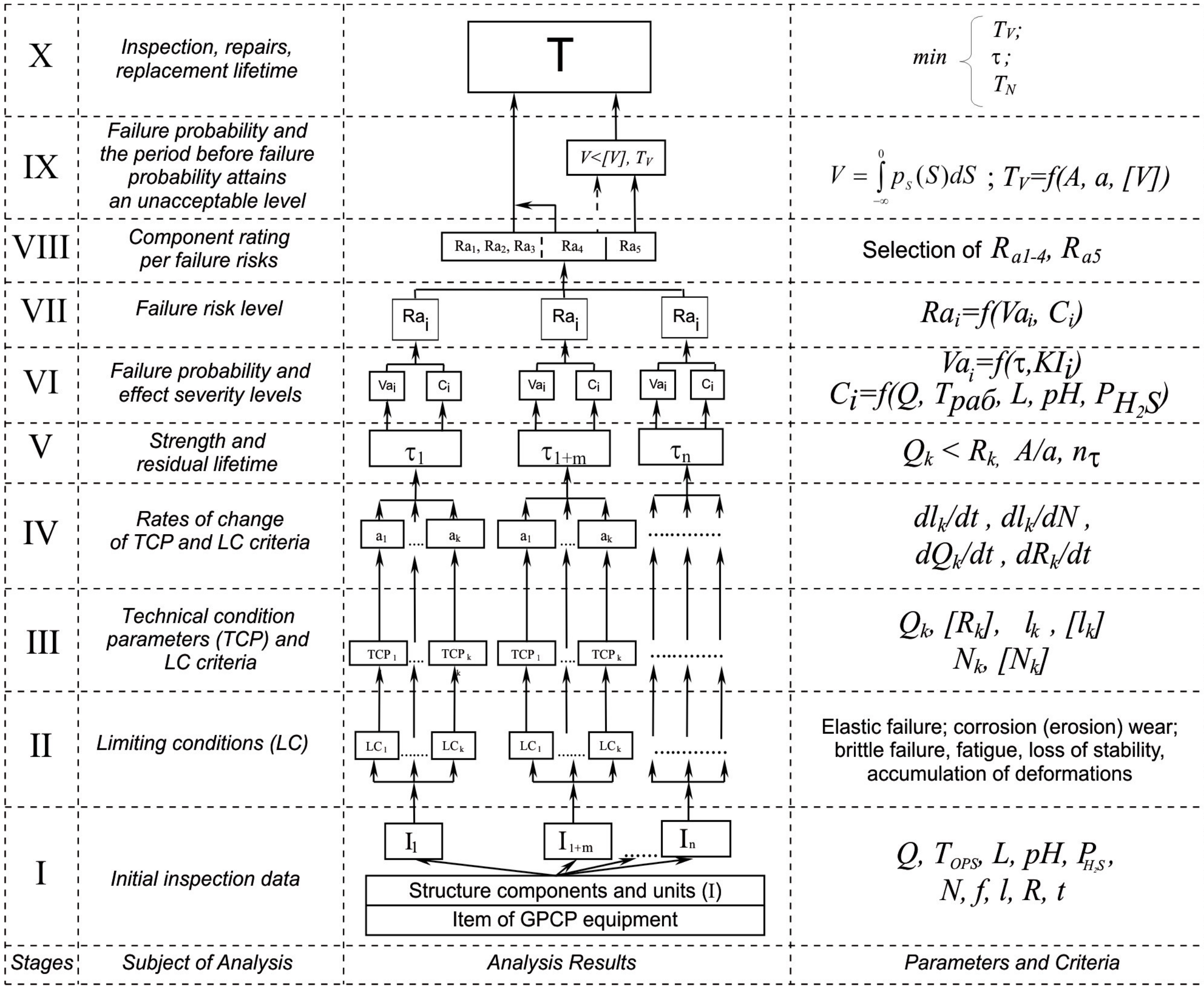
Option 2: T_V is calculated for components with Ra_5 (Ra_4)

$\Delta V_{F\ 1\text{-}4}$ – failure probability change by inspection results

ΔV_R – failure probability change due to defective component repairs

Fig.12. Options for establishing due dates of inspection of equipment by failure risk probability and hazard criteria

The model shown in Figure 13 was developed to analyse operating conditions of process equipment and plan out inspections of its components by failure probability and failure risk criteria.



Q - generalized load;
T_{OPS} - operating temperature;
L - design;
pH, P_{H_2S} - operating environment characteristics;
N, f - generalized operating conditions;
l - generalized defect characteristics;
R - generalized load-carrying capacity;
t – non-failure period from the beginning of operation;
Q_k, $[R_k]$, l_k, $[l_k]$, N_k, $[N_k]$ – current values of technical condition and limiting condition parameters;
a = dl_k/dt, dl_k/dN, dQk/dt, dRk/dt - rate of change of technical condition parameters;
τ - predicted value of residual lifetime;
A - difference between technical condition and limiting condition parameter values;
Va_i – failure probability level;
KI_i - examination quality level;
C_i - failure effect severity level;
Ra_i - failure risk level;
V - failure probability;
$p_S(S)$ - safe-load factor probability density;
[V] - acceptable level of failure probability;
T_V - time to attainment of [V];
T_N - operating period between inspections;
n_N, n_V - safe-load factors;
T - specified time to inspection, repairs, replacement

Fig.13. Model of analysis of operating conditions, failure risks, lifetime forecasting and planning of inspections of gas processing and chemical treatment equipment by hazard criteria and failure probabilities

IV. Gas processing and chemical equipment metal damages and fractures data evaluation and standard technical requirements analysis results made it possible to outline and resolve the problem of substantiation of adequacy of selected methods of control and quality of programmes for gas processing and chemical equipment inspection.

The selected options and classified methods of control are shown in Figure 14. The basic methods include Visual Inspection, Ultrasonic Flaw Inspection, Ultrasonic Thickness Measurements, liquid penetrant inspection, magnetic particle inspection and eddy-current flaw inspection, hardness tests, as well as computational methods.

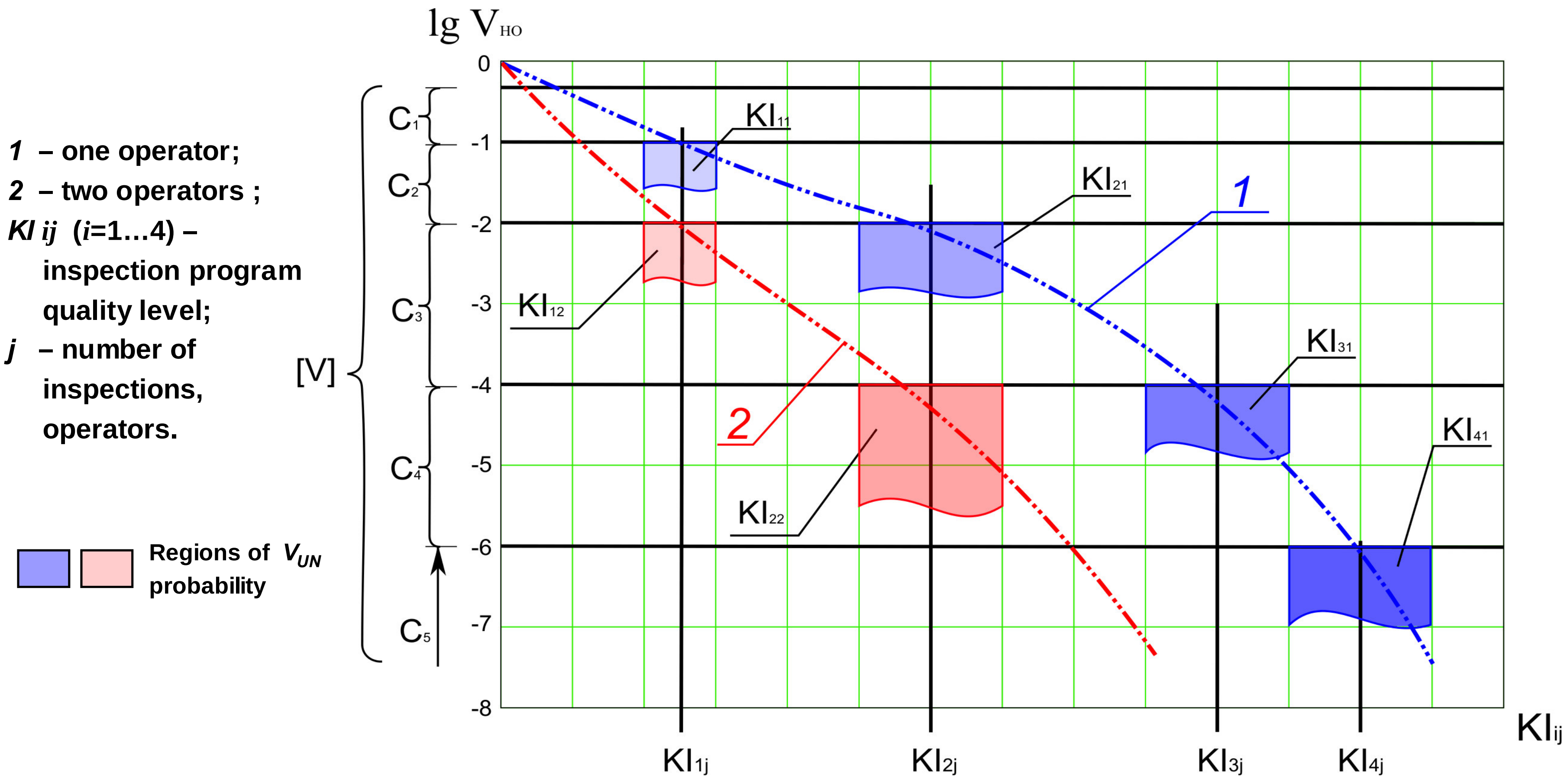
Methods of control	Surface defects					Internal defects			Physical and chemical properties of metal
	Cracks	Blistering	Corrosion thinning	Pitting, welding defects	Dents, burrs	Cracks	Lamination	Volumetric defect	
Visual inspection and measuring	2	3	2	3	3	-	-	-	-
Ultrasonic thickness measuring	-	3	3	1	-	-	2	-	-
Ultrasonic flaw inspection	3	-	2	1	-	3	3	3	-
Liquid-penetrant testing	3	-	-	1	-	-	-	-	-
Eddy current testing	3	-	-	1	-	-	-	-	-
Magnetic flaw detection	3	-	-	1	-	2	-	-	-
Sample-free hardness test	-	-	-	-	-	-	-	-	3
Metallography	-	-	-	-	-	-	-	-	3
Radiography	1	-	-	1	-	1	-	2	-
Thermal imaging inspection	1	1	-	-	-	-	-	-	-
Mechanical and other methods of laboratory testing of metal samples	-	-	-	-	-	-	-	-	3
Non-destructive spectral chemical analysis of metal	-	-	-	-	-	-	-	-	3

- - not applied;
1 – low efficiency (defect location without identification of values and (or) dimensions);
2 – average efficiency (defect location with validity of identified values and (or) dimensions of less than 70%);
3 – high efficiency (identification of defects or diversions of technical condition parameters having validity of identified values and (or) dimensions of no less than 70%).

(green) - main NDT methods

Fig.14. Results of selection and classification of methods of control by the level of identification of typical defects of gas processing and chemical treatment equipment

The diagram of dependence of inspection programme quality levels on the number of independent inspections by the defect undetectability criterion (V_{UN}) is shown in Figure 15. It has also become possible to identify levels of undetectability of potential defects below limiting values of equipment components failure probability, equation (4).



$$lg\ V_{UN}\ (KI_{ij}) \quad \Rightarrow \quad lg\ [V] \qquad (4)$$

Fig.15. Dependence of the defect undetectability criterion (V_{UN}) on the number of independent inspections

Equation (5) provides substantiation for inspection programme quality criteria for various equipment component failure hazard levels, whereat the probability to detect defects is not greater than the limiting value of component unreliability.

$$V_{UN}(Ra_i(C_i)) \le [V(C_i)] \quad , \quad i = 1 \ldots 5 \qquad (5)$$

where:

$Ra_i(C_i)$ – failure hazards in association with failure criticality levels;

$V_{UN}(Ra_i(C_i))$ – the probability of undetectability of defects in equipment components with the failure risk level of Ra_i by the failure criticality level C_i;

$[V(C_i)]$ – the acceptable value of failure probability for equipment components with the failure criticality level C_i

Figure 16 shows the model for evaluation of quality of inspection of equipment components with the predetermined undetectability of defects; the model was developed to prove the quality of inspection programmes for process equipment components by results of failure risk analyses.

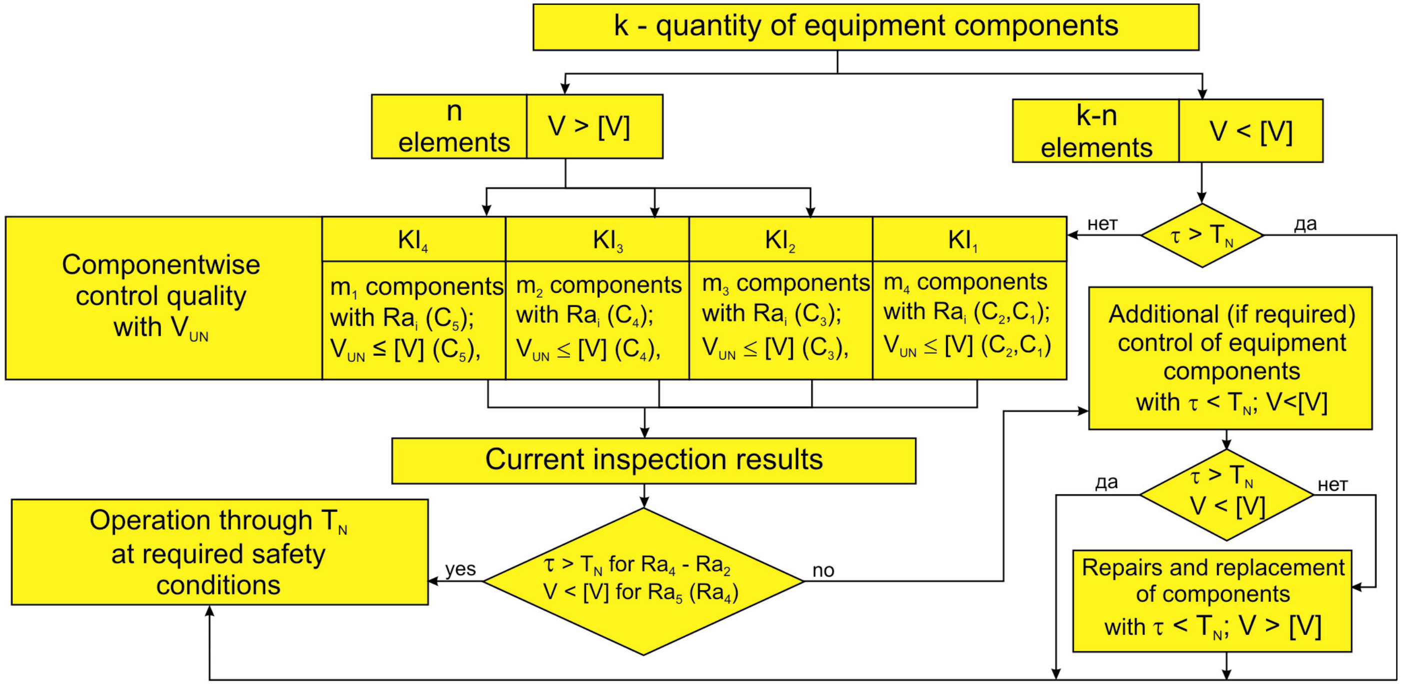


Fig.16. Model of substantiation of inspection quality levels for components of gas processing and chemical treatment equipment

V. NDT studies performed by some prominent scientists, wide experience, and existing standard techniques made it possible to outline and resolve problems concerning adjustment of instruments and control systems, enhancement of reliability of non-destructive testing of base metal, welds and improvement of mechanical properties of metal of structural elements of gas processing and chemical treatment equipment resistant to sulphide corrosion cracking. Figure 17 shows ultrasonic testing defectograms in lateral views, in cross sections, and the metallographic picture of a sample with hydrogen cracking at various settings of instrument sensitivity.

New ultrasonic test parameters for detection of hydrogen cracking, different from GOST 22727, which provide for detection of coalescence stages of hydrogen cracking with an inaccuracy not exceeding 10%.

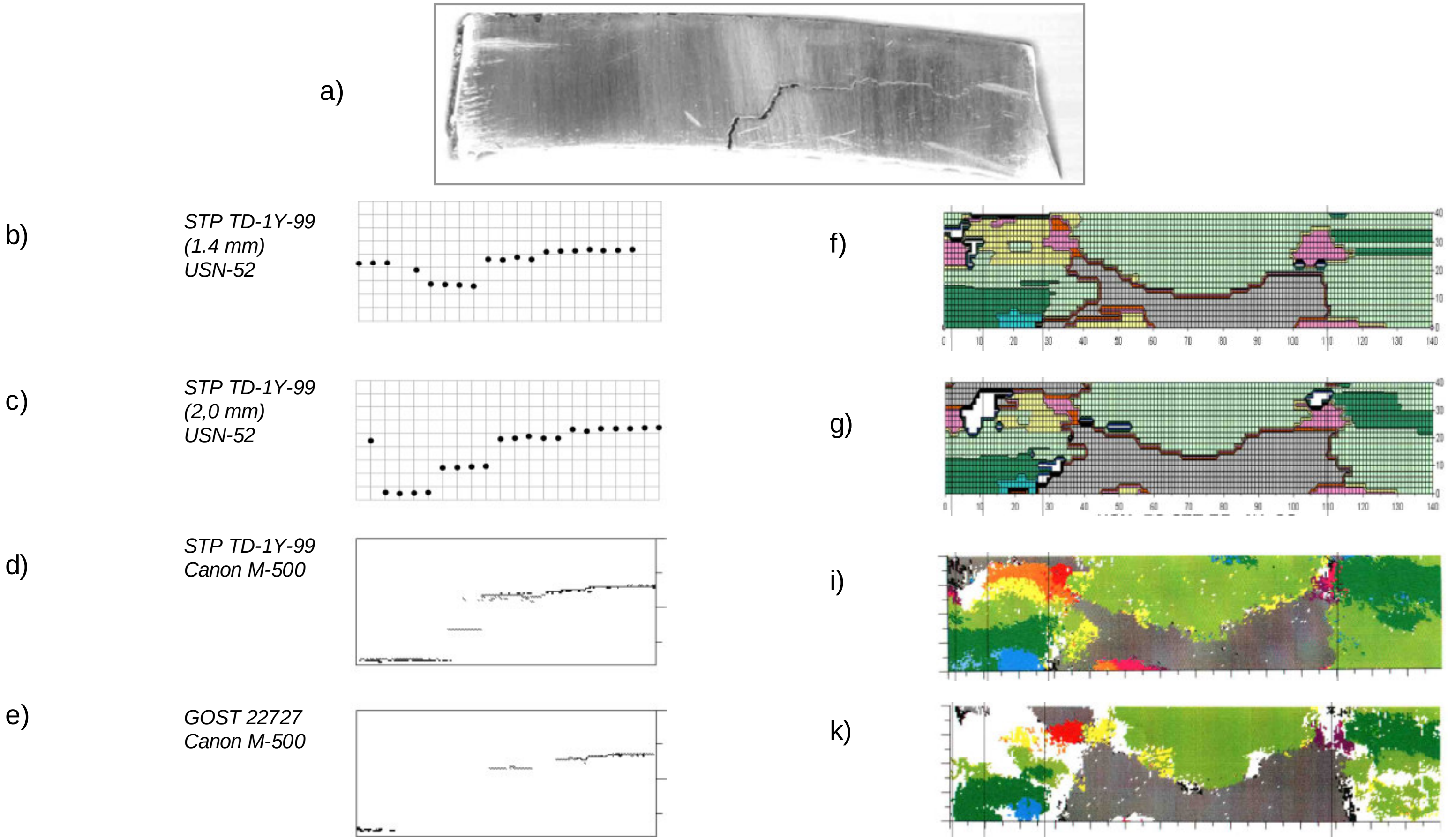
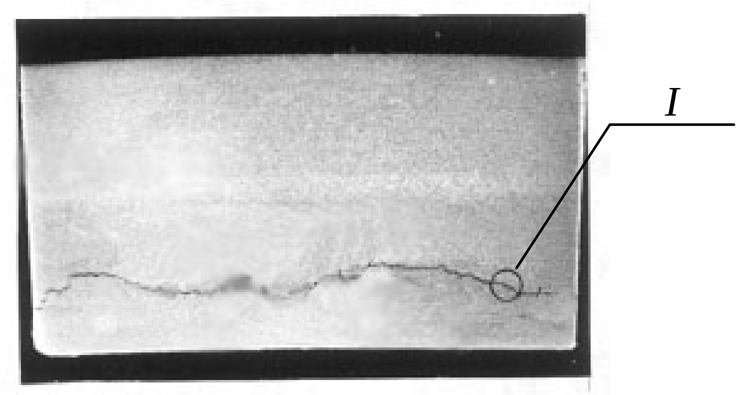
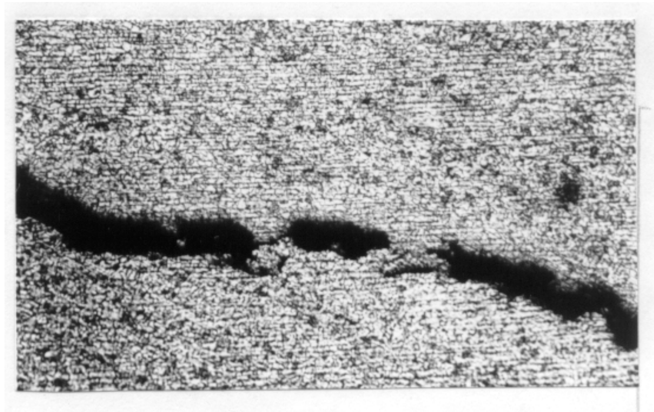


Fig.17. Ultrasonic studies of hydrogen cracking-like defects. “a” – defective pipe cross section; “b”, “c”, “d”, “e” – defectograms “in cross section” with the sensitivity of 1.4mm, 2.0mm, 2.0mm, 3.0mm respectively; “f”, “g”, “i”, “k” – defectograms “in views” with the sensitivity of 1.4mm, 2.0mm, 2.0mm, 3.0mm respectively.

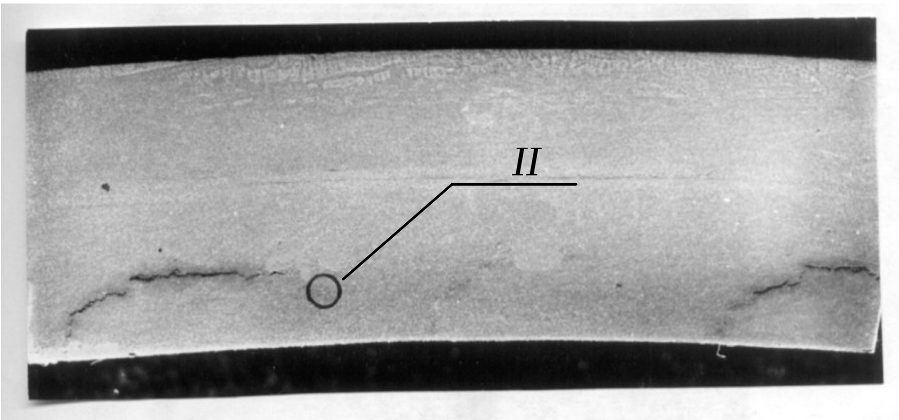
Typical damages caused by hydrogen cracking in pipeline walls detected as a results of ultrasonic testing are shown in Figure 18.



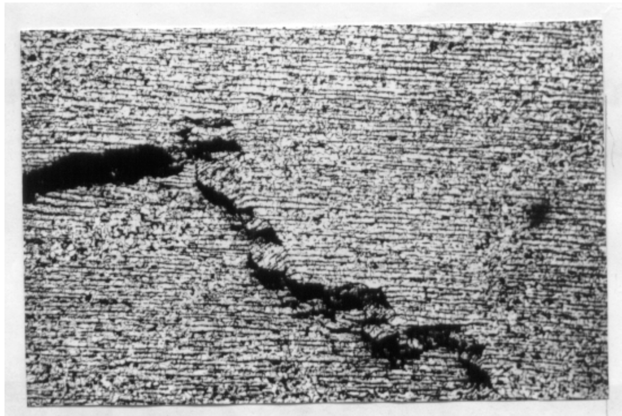
a) typical failure caused by hydrogen cracking, 2 x magnification



b) segment I, 63 x magnification



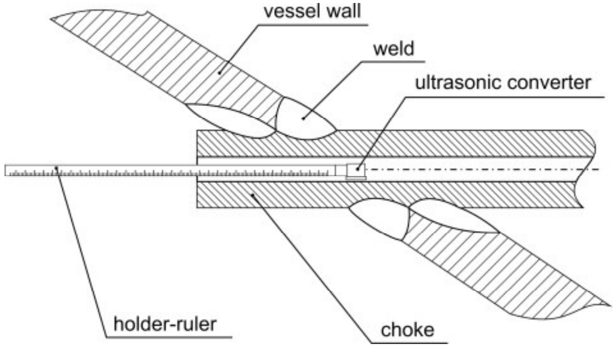
c) typical failure caused by hydrogen cracking, 2 x magnification



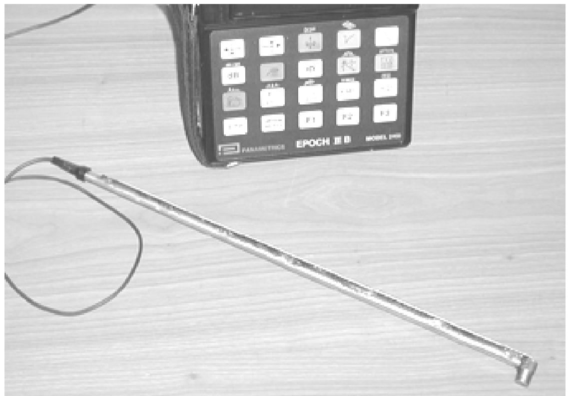
d) segment I, 63 x magnification

Fig.18. Typical failures of metal caused by hydrogen cracking in H_2S-bearing feed stream pipeline wall

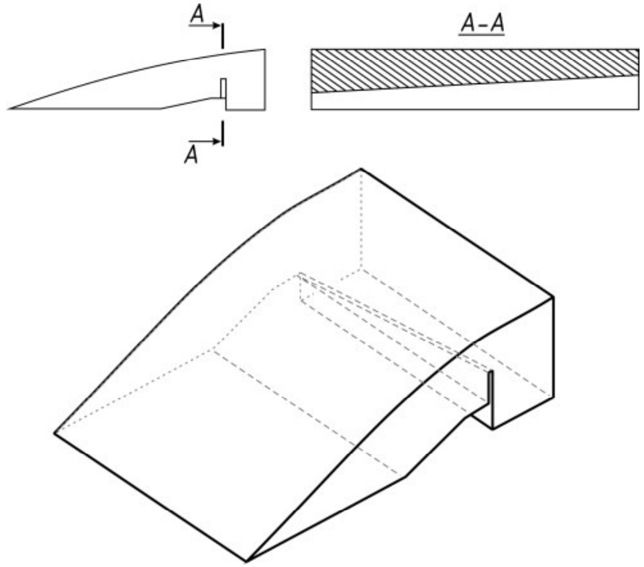
Figure 19 shows tools and samples used to carry out ultrasonic inspections and define discontinuity flaw parameters of socket welded connections of small-diameter chokes (up to 100 mm in dia) with accuracy of no less than 0.7 and of tangential chokes, which have not been monitored before as it was not required by regulatory documents. Over 3,000 similar choke connections located on gas processing and chemical treatment vessels were for the first time inspected for defects. Discontinuity flaws were found in more than 1,000 choke connecting welds. Over 500 socket welds have been repaired, and others are being monitored under service conditions depending on the results of strength analyses and life predictions.



Ultrasonic tester of branch pipe joint welds



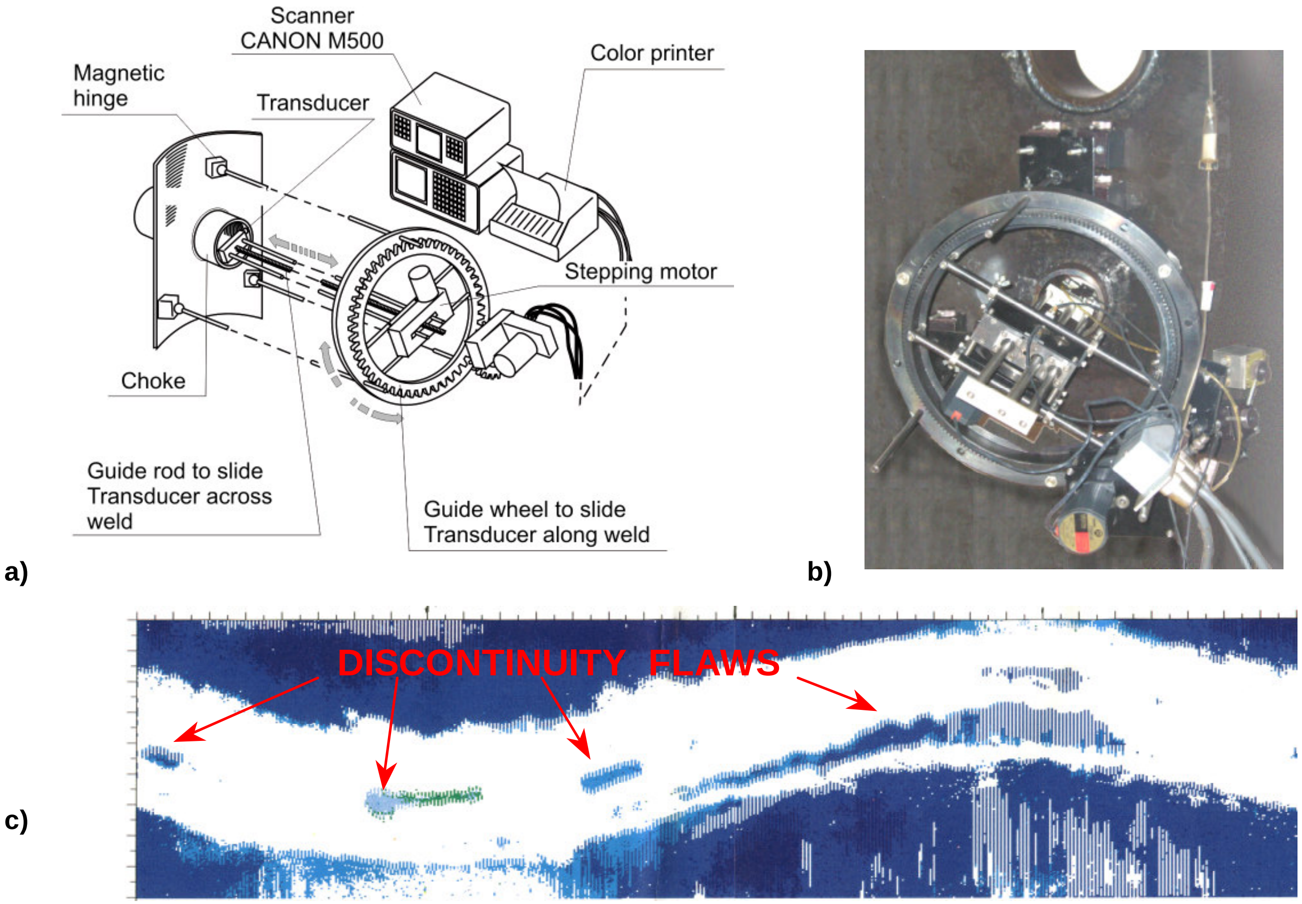
Flaw detector EPOCH-IIIB with accessories



Sample simulator with crack-like defects of various depths

Fig.19. Tools and samples for adjustment of ultrasonic testing equipment and enhancement of detectability of discontinuity flaws in joint weld of process vessel

The equipment shown in Figure 20 is used to monitor the condition of choke corner welds having discontinuity flaws; the device is designed for carrying out automatic inspections of welds and their conditions by comparing defectograms.



«a» - equipment components layout, «b» - equipment design ,
«c» - defectogram of tangential choke socket weld

Fig.20. Equipment for automatic ultrasonic scanning

New correlation dependences (6, 7) such as “hardness-yield strength ($\sigma_{0.2}$)” and “hardness – tensile strength (σ_T)” (Picture 21 a, b) for corresponding instruments, and conditions of hardness measurement for using ‘no-sample’ methods and instruments, which enable ultimate strength control with an error not exceeding 5% and yield strength control with an error not exceeding 9% for H_2S –resistant steels of gas processing and chemical treatment installations over a long period of operation (Figure 21 c), have been established as follows:

$$\sigma_{0.2} = -5{,}471 \cdot 10^{-3} \cdot HV^2 + 3{,}808 \cdot HV - 91 \quad (6)$$

$$\sigma_T = -5{,}31 \cdot 10^{-3} \cdot HL^2 + 6{,}118 \cdot HL - 1080 \quad (7)$$

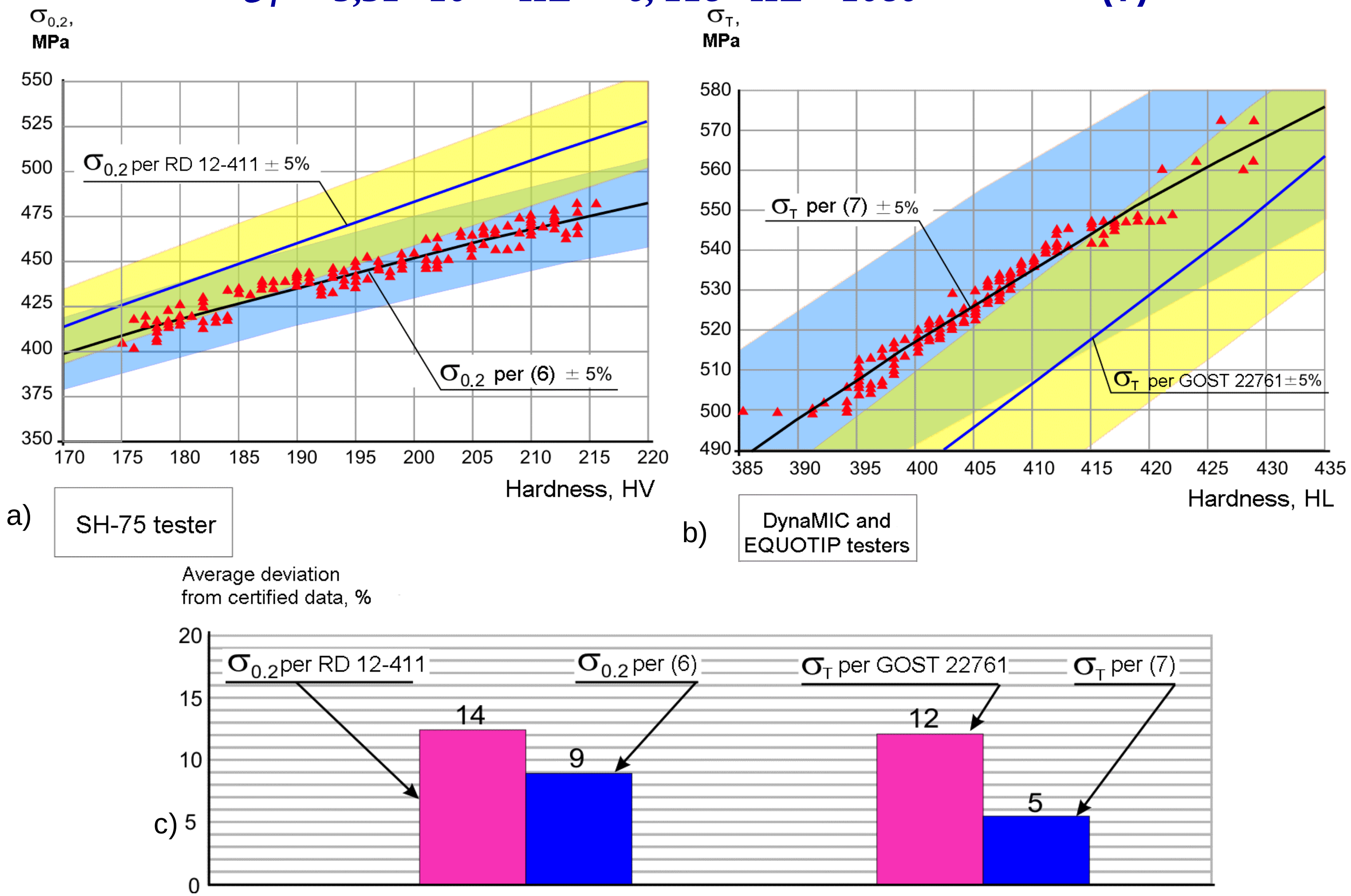


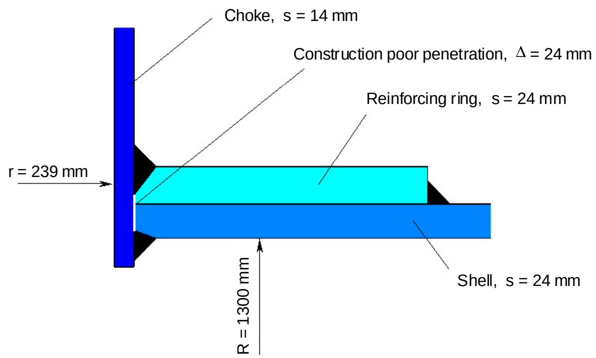
Fig.21. Plots of “hardness - $\sigma_{0.2}$” (a) and “hardness - σ_T” (b) against estimation error of - $\sigma_{0.2}$ and σ_T (c)

VI. On the basis of standard techniques and research works of some prominent scientists it has become possible to formulate and resolve the issue of conducting strength and lifetime analyses of equipment components with the most common defects; this also allowed substantiation of failure probability parameters and risk assessment criteria.

Figure 22 shows the results of strength testing of a full-size vessel with incomplete fusion in the manhole weld, where the size of incomplete penetration is equal to the shell wall thickness. Actual deformations have been compared with designed ones.

GASOLINE TANK CAR AFTER TESTING

CROSS-SECTION OF DEFECTED AREA OF WELDED JOINT BETWEEN MANHOLE AND SHELL



“PRESSURE-DEFORMATION” DEPENDENCE FOR SHELL

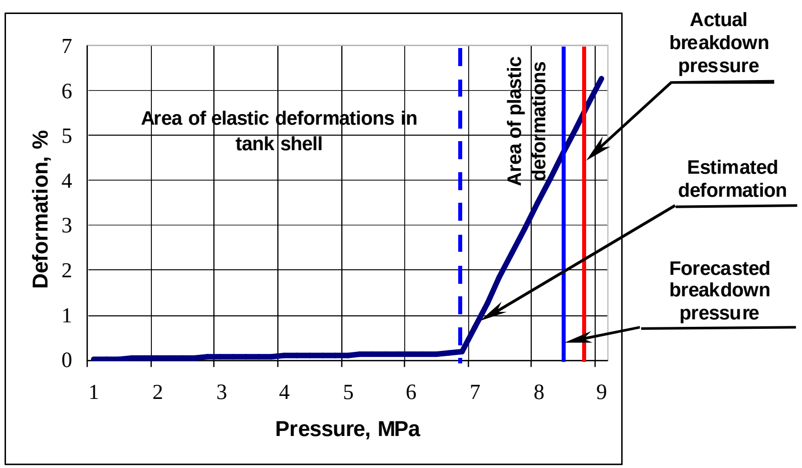


Fig.22. Design and experimental strength analyses. Results of strength testing of a propane-butane railway tank-car with a defective manhole weld

Figure 23 shows the findings of strength testing of a vessel with defects in choke welds.

Research works indicated that computational methods applied in integrated computer programmes such as LS-DYNA, COSMOS, can ensure fair reliability of results of strength and lifetime assessment of gas processing and chemical equipment components having various defects with deterministic and probabilistic target setting. The allowance inaccuracy is 5 to 15% for operating pressures and 5 to10% for limiting pressure. Incomplete fusion in choke welds does not result in ultimate limit state of the element operating under static and quasi-static load conditions, provided that sizes of welds does not exceed allowable GOST 5264 limits.

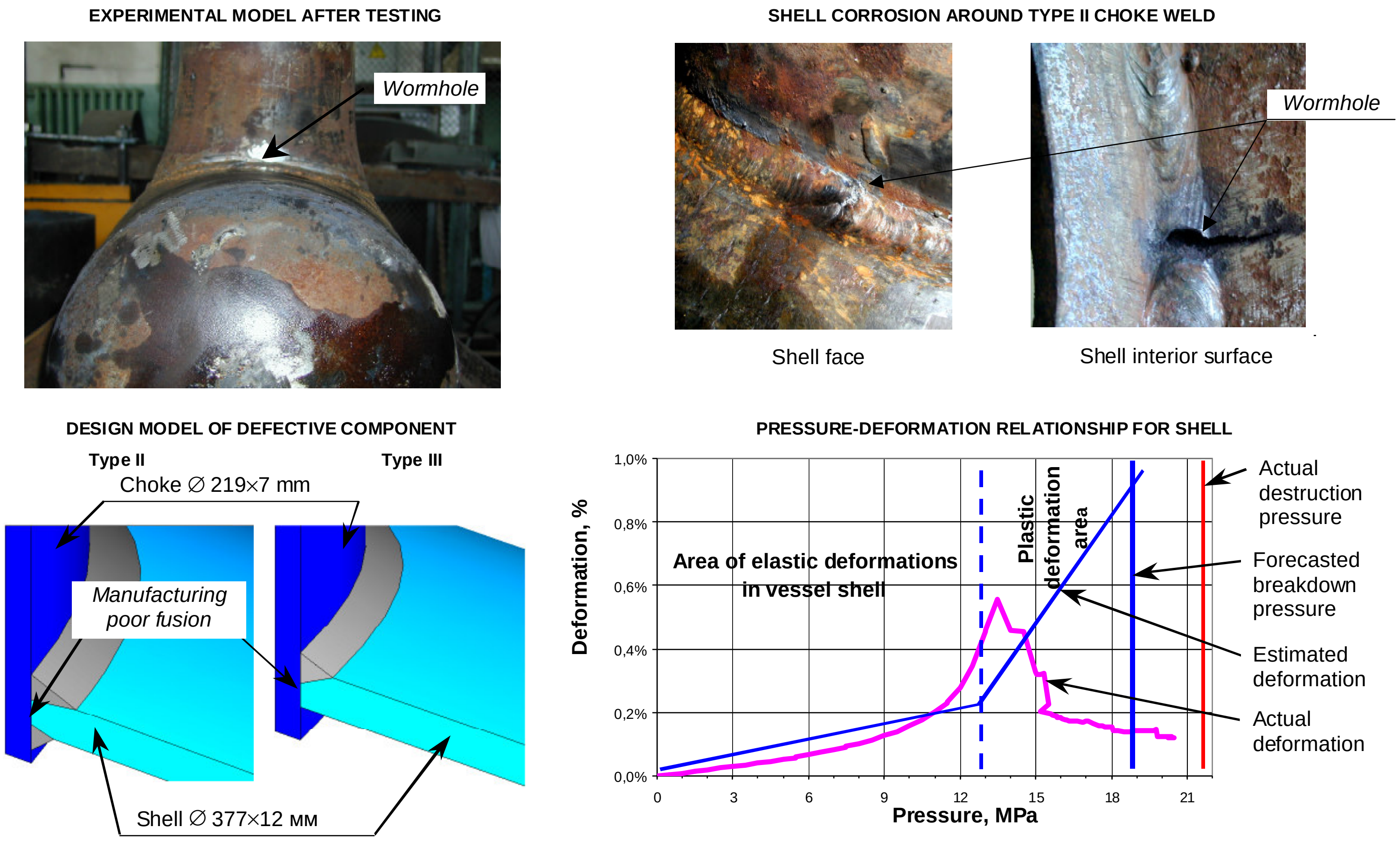
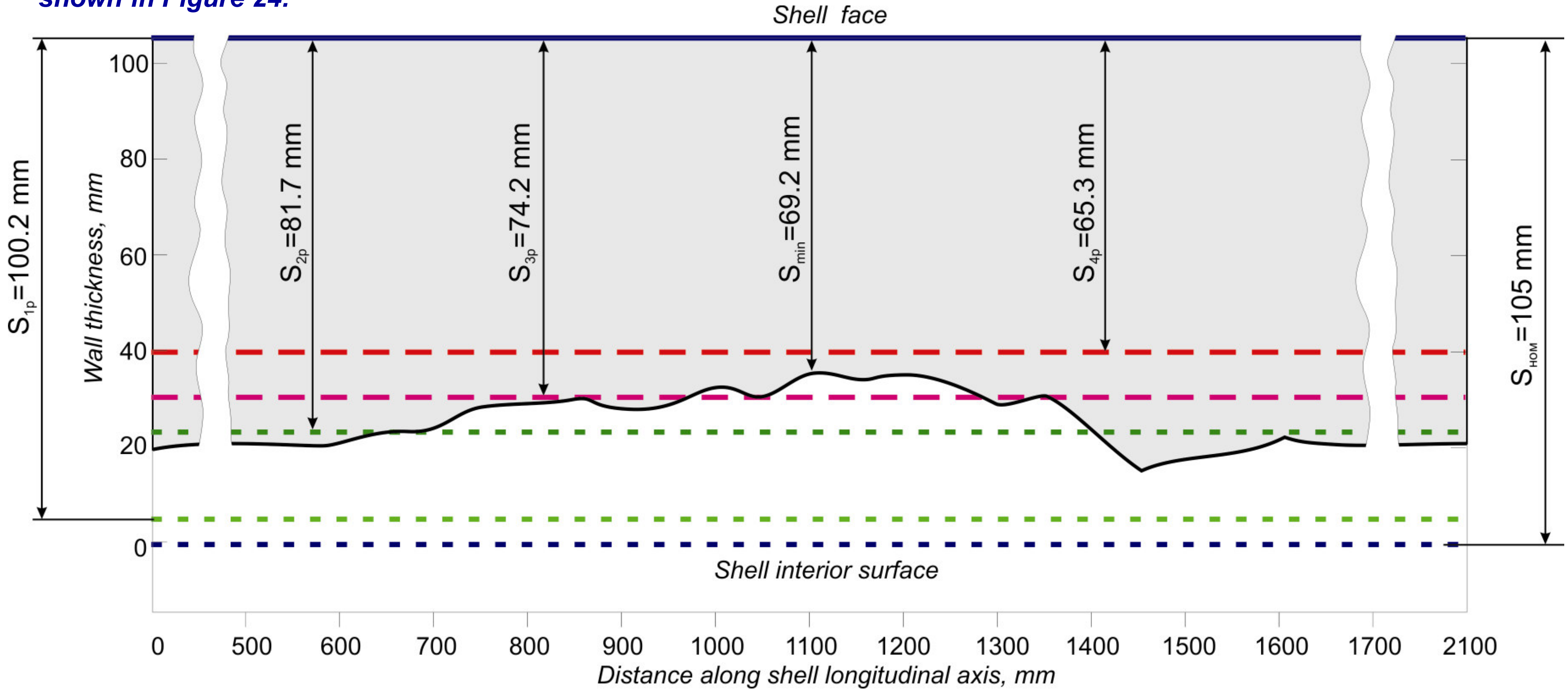


Fig.23.Design and experimental strength analyses. Results of strength testing of a sample vessel with defective choke socket welds

The lifetime (τ) and failure probability (V) analysis was made on the basis of initial data obtained from measurements of sixty absorber shells of Astrakhan GPP having various rates of wall wear. Wall wear examples are shown in Figure 24.



***Sном* – nominal effective wall thickness;**

***S_{1p}* – specified absorber shell wall thickness as per design (Pspec=74 kgf/cm²);**

***S_{2p}* – effective wall thickness operating pressure (Pops=60kgf/cm²) with regard to standard mechanical properties of metal;**

***S_{3p}* – effective wall thickness operating pressure (Pops=60kgf/cm²) with regard to actual properties of metal;**

***S_{4p}* – effective wall thickness operating pressure (Pops=60kgf/cm²) with regard to actual properties of metal and reduction of safety factor (without regard to H_2S impacts, for temporary operation);**

***S_{min}* – minimal measured wall thickness**

Fig.24 AGPP absorber shell wear (thinning)

The analysis is based on the classical dependence (by V.V. Bolotin and other authors) of failure probability and trouble-free operation of equipment components on non-failure operating time (operational life) and rapture life (Figure 25). From this dependence it is evident that equipment (construction elements) with longer rapture life will have lower failure probability.

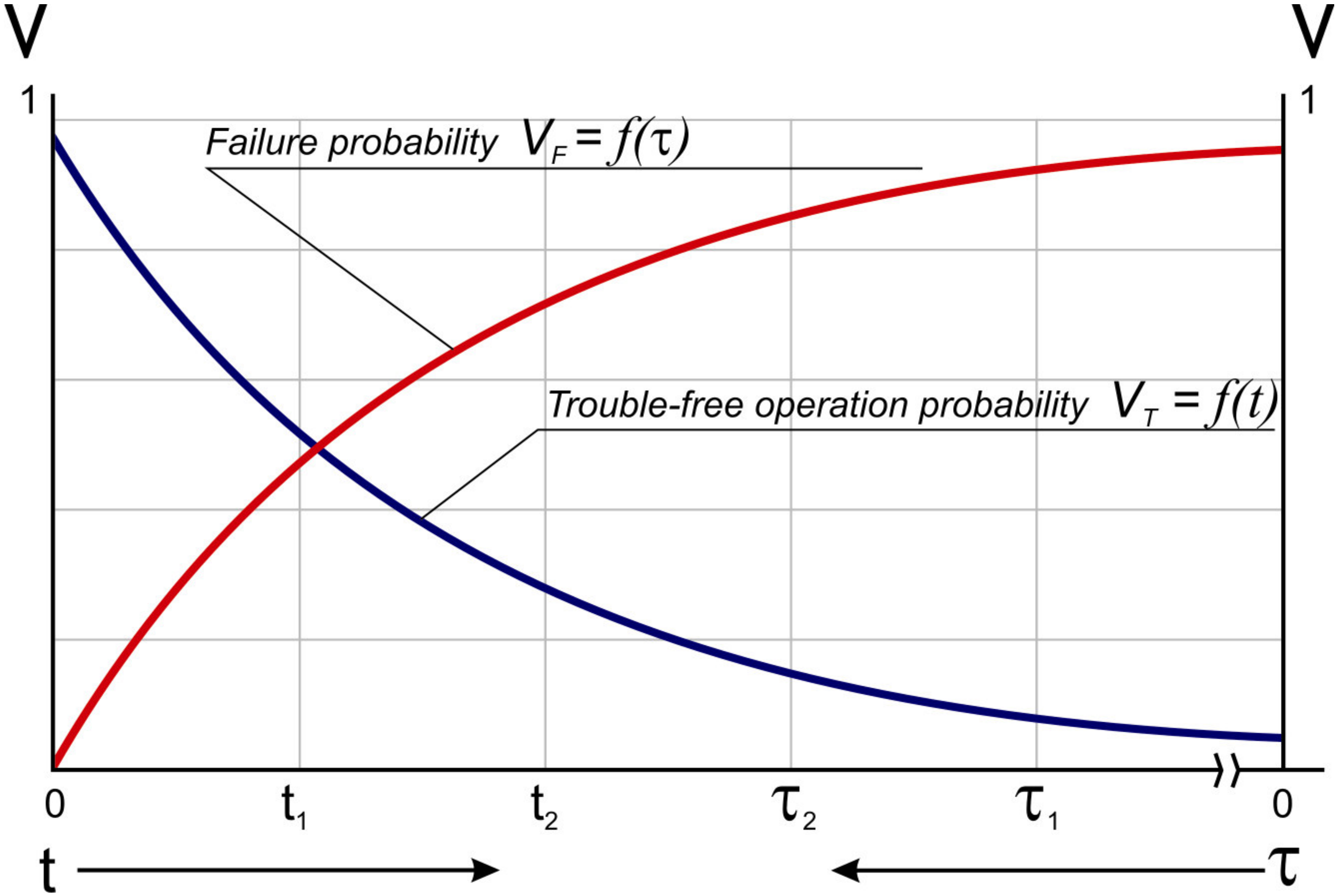
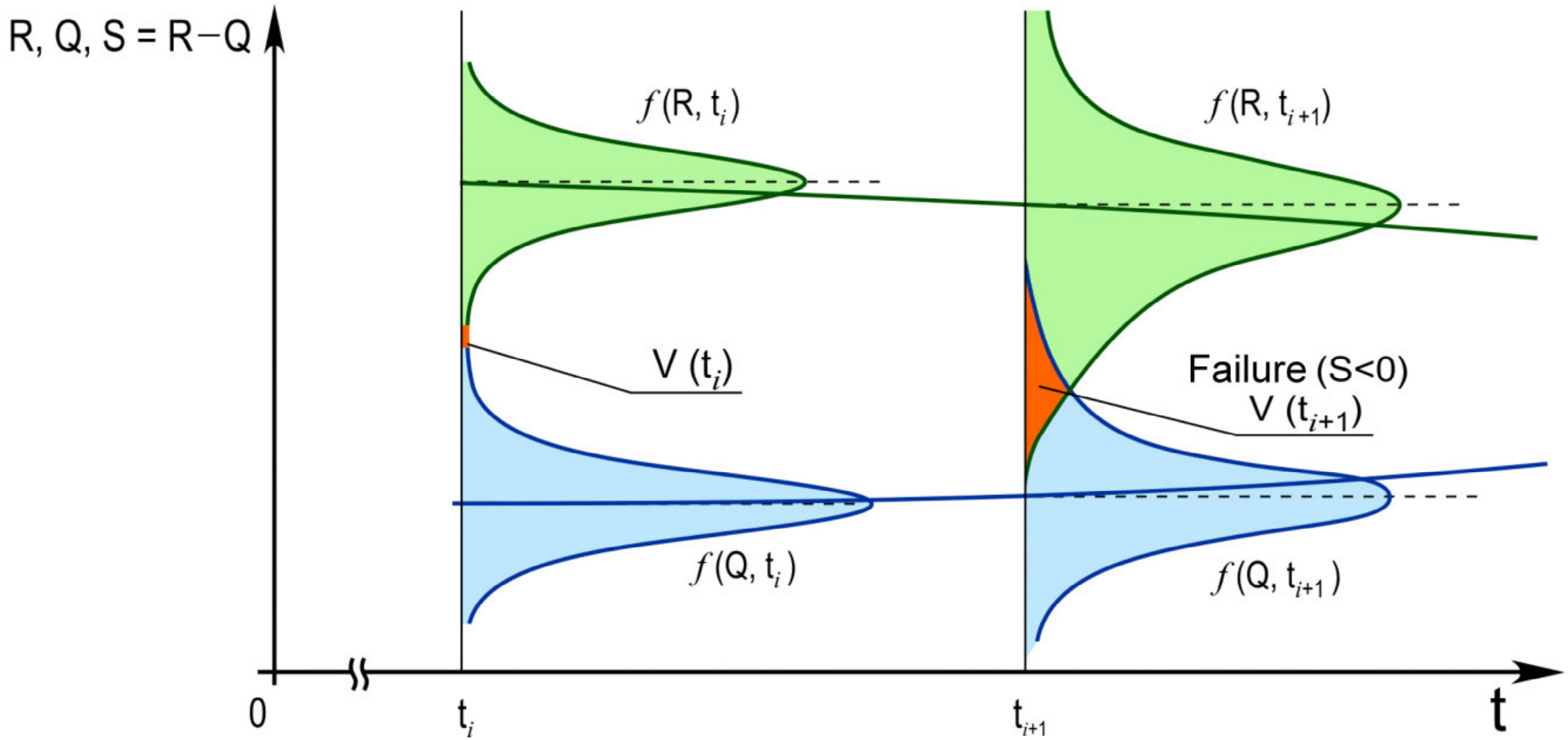


Fig.25. Graph showing dependence of failure probability (V_F) and trouble-free operation (V_T) on non-failure operating time (t) and rapture life (τ) of equipment components

The general graphical representation of the "probability statistics" method of assessment and forecasting of failure probability for process equipment components is shown in Figure 26 as variations (random variables) of statistical characteristics of strength and load.



R – ***generalized strength characteristics;***

Q – ***generalized load characteristics;***

S – ***generalized safe load factor;***

t_i, t_{i+1} – ***reference time points.***

Fig.26. Graphic illustration of the "probability statistics" approach to evaluation and forecasting of failure probabilities

Recent works indicate the availability of intimate correlation relationship between failure probability (lgV) and designed operational life (τ) of equipment components with a coefficient of up to -0.9 before limiting condition occurs. The relationship graph is shown in Figure 27. By plotting failure probability acceptable value zones and zones of τ division into the areas multiple of standard operating time (T_N) between inspections of gas processing and chemical treatment equipment onto the present «lgV to τ» relationship diagram, it becomes possible to identify failure risk areas for equipment components with various defects with regard to each potential failure criticality. Figure 27 shows the diagram for failure criticality level C_5. The similar graphs have also been plotted for failure criticality levels C_4, C_3, C_2, C_1.

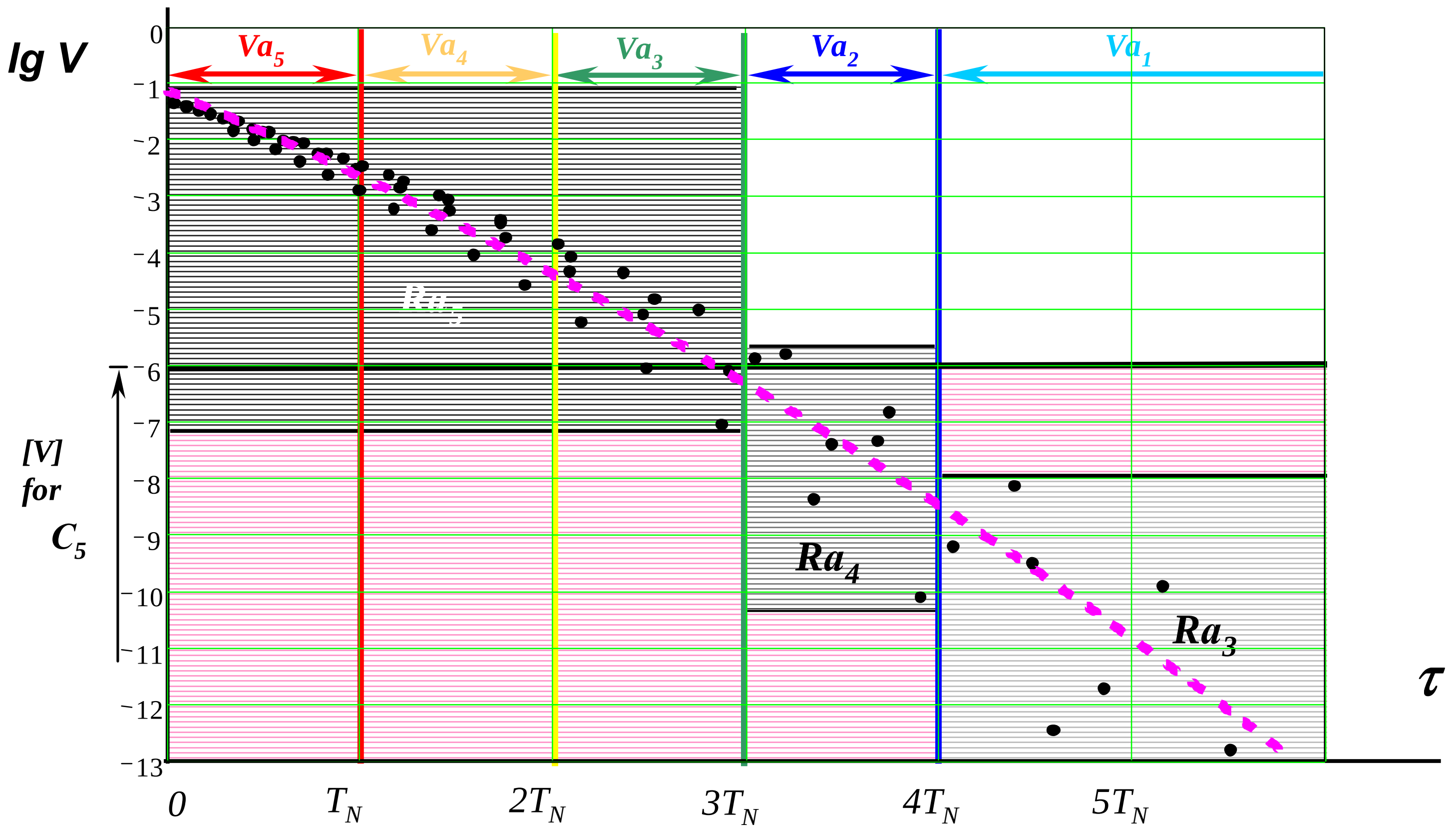


Fig.27.Graph showing V versus τ dependence and areas of failure risk levels by failure criticality level C_5

Figure 28 presents the combined matrix graph of a semi-quantitative failure risk analysis of defective gas processing and chemical equipment components by probability criteria and failure severity levels. The matrix graph is built by overlapping plots and zones of failure risk levels.

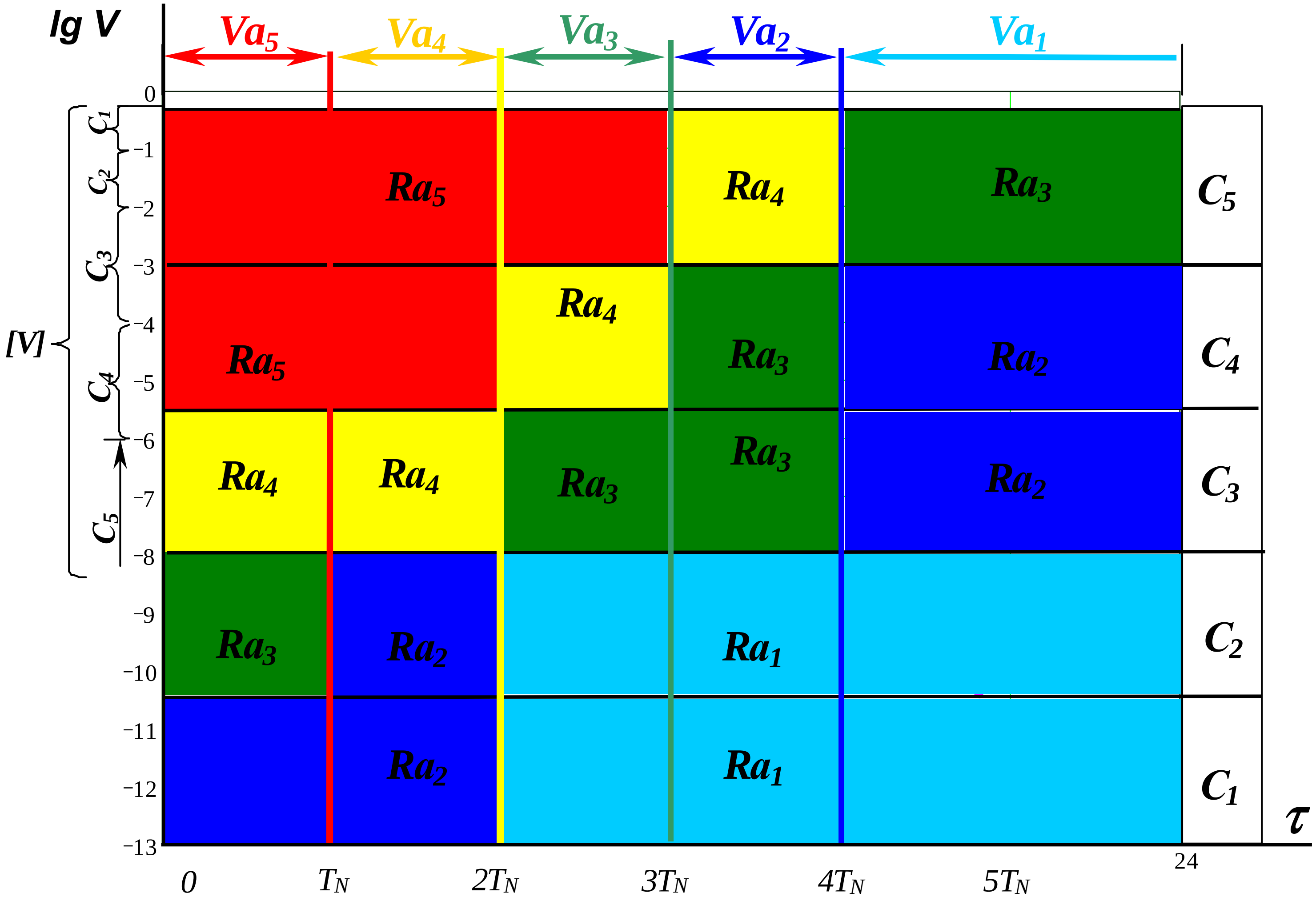


Fig.28. Combined matrix graph of equipment component failure hazard areas

VII. The problem of database development (see Table in Figure 29) for systematisation of initial and analytical data on equipment components condition and their classification by stress loading and residual operational life parameters, defect types, failure risks and failure probability levels, useful life until next inspection, repairs or replacement, was outlined and then successfully resolved for the purpose of effective management of huge data files on gas processing and chemical installations.

INITIAL AND ANALYTICAL DATA OF EQUIPMENT CONDITION

Initial data	Analytical data of actual condition	Analytical data on high failure risk equipment
- actual make - design - operating environment and parameters - inspection results - repairs and replacements	- failure mechanisms and technical condition parameters - basic failure mechanisms - limiting conditions - safety load and service life - probability levels - failure effect severity and failure risk - specified lifetime till next inspection	- by basic failure factors and most defective components - failure probability limiting value attainment estimate - specified lifetime till next inspection, repairs, replacement

EQUIPMENT RATING

By stress loading		
High	Average	Low

By product corrosion activity		
High	Average	Low

By temperature		
High	Average	Low

By failure mechanism			
Brittleness	Fatigue	Corrosion	No wear

By probable failure type				
Product leak (local corrosion)	Product leak (cracking)	Brittle failure	Deformation	Loss of stability

By failure probability and failure effect severity levels				
5	4	3	2	1

By risk level				
High	Above average	Average	Low	Very low

Till next inspection, repairs, replacement					
Up to 1 month	Up to 6 months	Up to 1 year	Up to 4 years	Up to 8 years	Up to 12 years

Fig.29. Initial and Analytical Data Systematisation Table for Gas Processing and Chemical Equipment

As an example of the data retrieval, Figure 30 shows the distribution of vessels of Orenburg gas field department by failure severity, probability and risk levels.

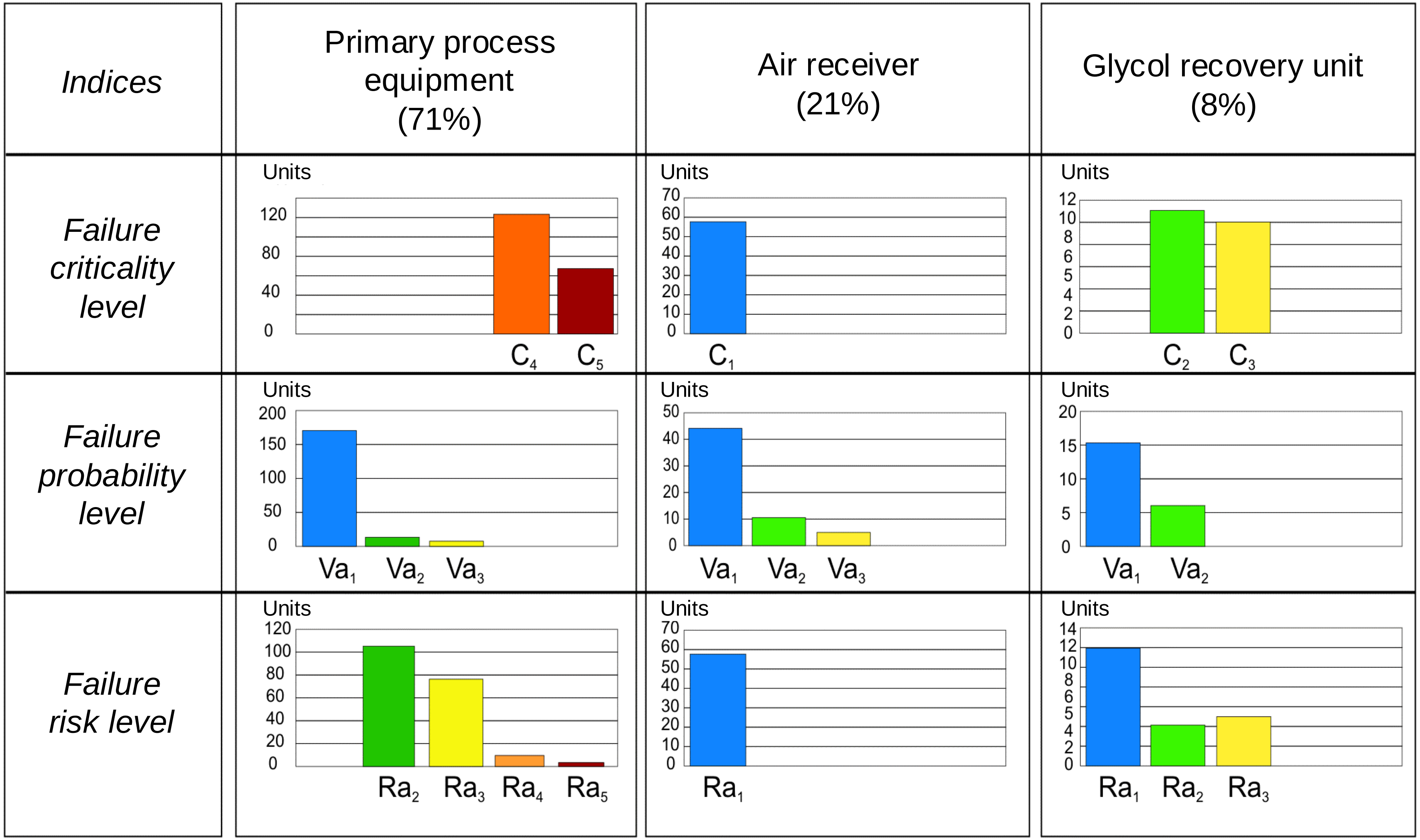


Fig.30. Distribution of vessels of Orenburg Gas Processing Plant by failure risk, probability and criticality

Technical solutions made by using the database potential enabled the development of the conceptual scheme of a closed cycle of database information traffic during the process of controllable operation of defective equipment components (see Figure 31) for the purposes of safety management of gas processing and chemical equipment operation by failure probability and risk criteria.

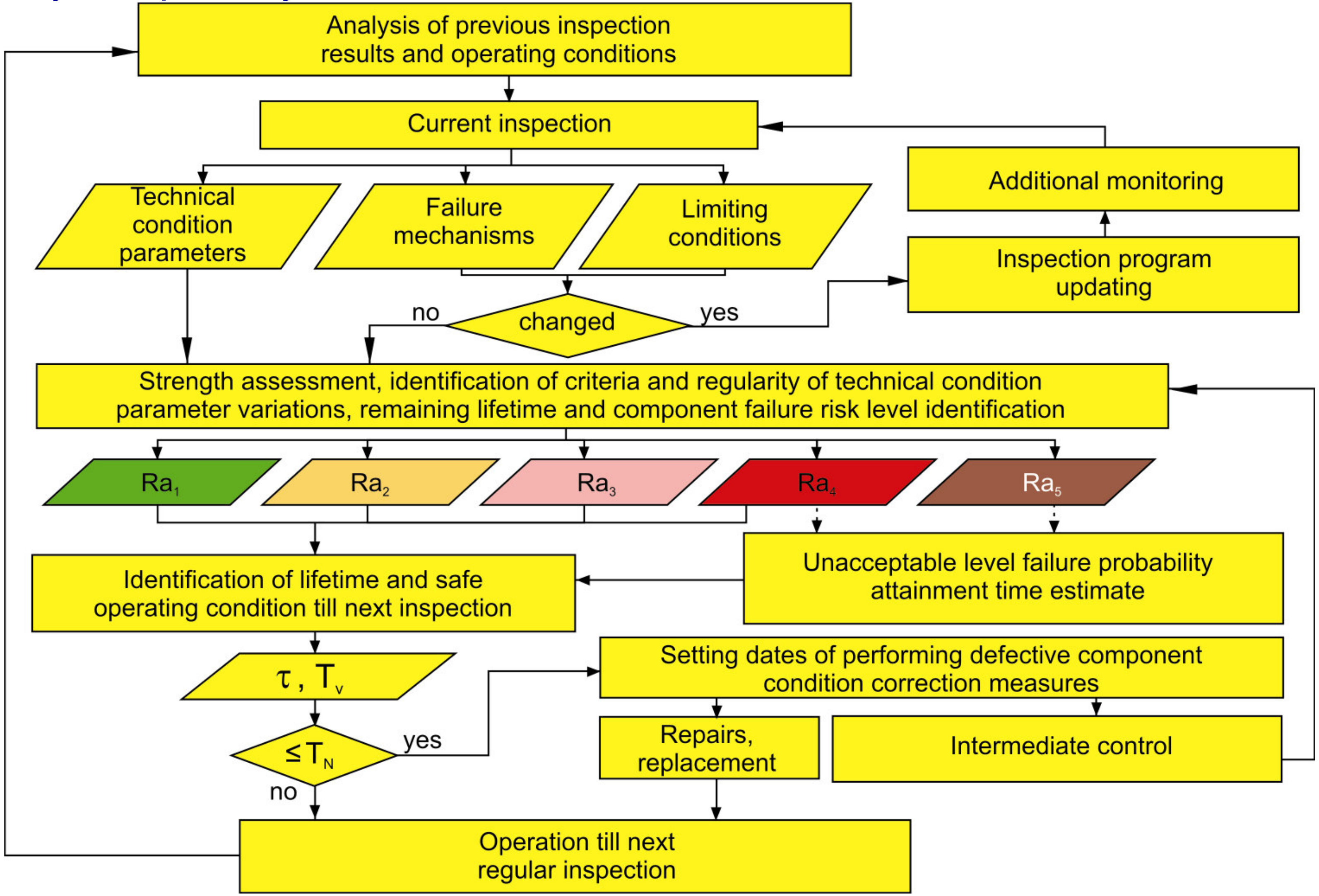


Fig.31. Closed cycle of information traffic during controllable operation of equipment components by risk criteria and failure probability

VIII. In order to ensure a regulatory background for the above system, the following norms and standards have been prepared and put into effect with regard to inspection and repairs of process equipment operating in hydrogen sulphide environments:

1. ***Procedure of Arrangement of Condition Monitored Maintenance, Repairs and Replacement of Own Fixed and Leased Assets of LLC Orenbourggazprom (app. by JSC "Gazprom" on Jan.27, 2003, agreed by Gosgortechnadzor of Russia on Nov. 15, 2002);***

2. ***Astrakhan Gas Processing Plant Equipment Diagnostics Procedure (app. by JSC "Gazprom" on June 01, 1996, agreed by Gosgortechnadzor of Russia on May 30, 1996);***

3. ***Procedure of Diagnostics of Orenbourggazprom Process Installations and Equipment Operating in H_2S Corrosion Environment (app. by JSC "Gazprom" on May 30, 1998, agreed by Gosgortechnadzor of Russia on May 27, 1998);***

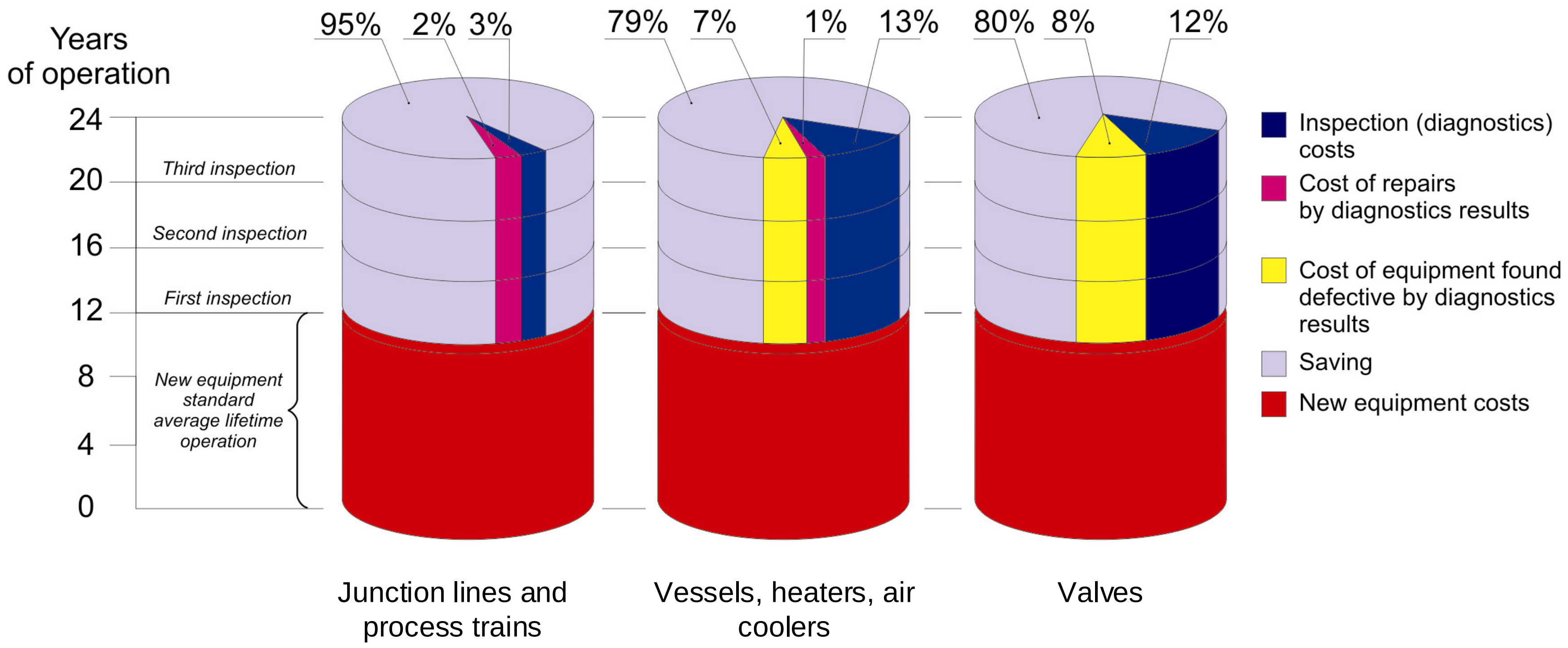
4. ***JSC Gazprom Oil and Gas Processing Plants Equipment and Pipeline Diagnostics Procedure (app. by JSC "Gazprom" on Dec.16, 2000, agreed by Gosgortechnadzor of Russia on Dec. 5, 2000);***

5. ***JSC Gazprom Oil and Gas Plant Fixed Production-Related Assets Repairs Procedure (app. by JSC "Gazprom" on Dec.16, 2000, agreed by Gosgortechnadzor of Russia on Dec. 5, 2000);***

6. ***Methods of diagnostics of technical condition of wellhead X-trees operating in H_2S-bearing environments at JSC Gazprom gas producing facilities(app. by JSC "Gazprom" on Dec.23, 2000, agreed by Gosgortechnadzor of Russia on Dec. 20, 2000);***

7. ***Factory standards, guidelines and provisions, establishing special requirements for NDT types, training and certification of NDT specialists, checking strength calculations and quality of work.***

IX. The results of the analysis given in Figure 32 show the economic efficiency of the proposed system due to extended operation of gas processing and chemical treatment equipment beyond its service life regardless to financial and other losses caused by failures, accidents and emergencies.



Conditions: **- average standard operation life of new equipment is 12 years;**
- standard operation life between inspections is 4 to 12 years.

Conclusion: **- by now, as per inspection results, costs saving due to process equipment operation life extension is 80-95% of the cost of new equipment .**

Fig.32. Orenburg gas processing plant equipment inspection cost efficiency analysis

X. The present philosophy and applied system allowed for developing the scheme of optimisation of methods, volumes and terms of equipment inspection (see Figure 33) by means of correction of equipment condition and defective element failure risks. Calculations done and implementation of the above concept and system show the possibility to redistribute up to 50% of assets of an Operator (operating organisation) from equipment components with failure risk level Ra_1, Ra_2 to components with risk level Ra_5, Ra_4, Ra_3.

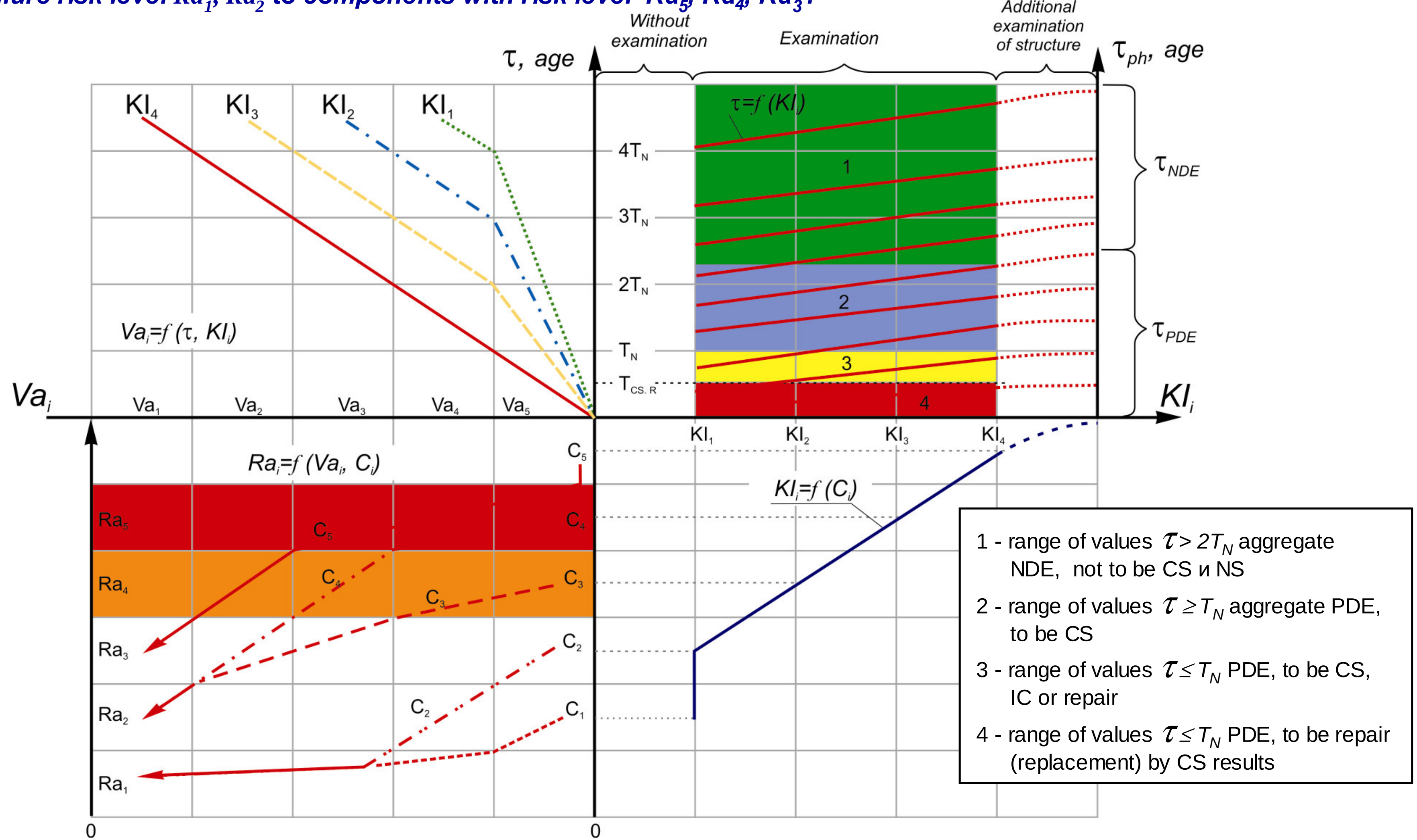


Fig.33. Scheme of optimisation of methods, volumes and terms of equipment inspection by means of correction of gas processing and chemical equipment condition by [V] and T_N criteria

XI. Our specialists have created and continue developing extensive scientific and technical assets, which allows them to carry out required research, diagnostic and expertise works (see Figures 34-38). They carry out the following non-destructive tests:

- ***ultrasonic inspection (Figure 34);***
- ***visual inspection and measurements (Figure 35 a);***
- ***liquid penetrant inspection (Figure 35b);***
- ***magnetic particle flaw detection (Figure 35c);***
- ***spectral analysis of chemical composition of metals, steel type identification (Figure 35d) ;***
- ***eddy current inspection (Figure 35e);***
- ***hardness test (Figures 35 f, g);***
- ***acoustic emission test (Figure 35 h);***
- ***magnet-anisotropic analyses of strained and deformed states (Figure 35 i);***
- ***thermal inspection (Figure 35 k);***
- ***metallographic test (Figure 36);***
- ***pump and compressor vibration survey (Figure 37);***
- ***subsurface pipeline diagnostics and repairs (Figure 38).***

a) b) c)

Fig.34. Ultrasonic testing equipment: a) ultrasonic flaw detector (defectoscope) USN-52; b) ultrasonic flaw detector (defectoscope) Epoch-IIIB; c) ultrasonic scanner Canon M500/600

a)

b)

c)

d)

e)

f)

g)

h)

i)

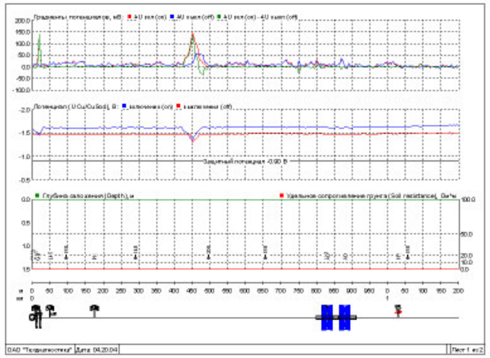
k)

Fig.35. NDT Tools and Equipment: a) instrument kit for visual inspections and measurements; b) liquid penetrant flaw inspection kit; c) magnet particle flaw detector Y-6; d) metal composition spectrum analysis kit SPECTROPORT-F; e) eddy current flaw detector LOCATOR UH-B; f) sample-free hardness tester; g) stationary hardness tester HBRV-187.5; h) acoustic emission tester A-Line 32D; i) Complex 2.05 Analyser for MD monitoring MD k) infrared image converter “Thermo Tracer TH 5104”

a) b)

Fig.36. Metallographic Testing Equipment:
a) portable microscope MMPU; b) scanning electron microscope AVT-32

Fig.37. Vibration Testing Equipment:
Vibration Analyser AU-014



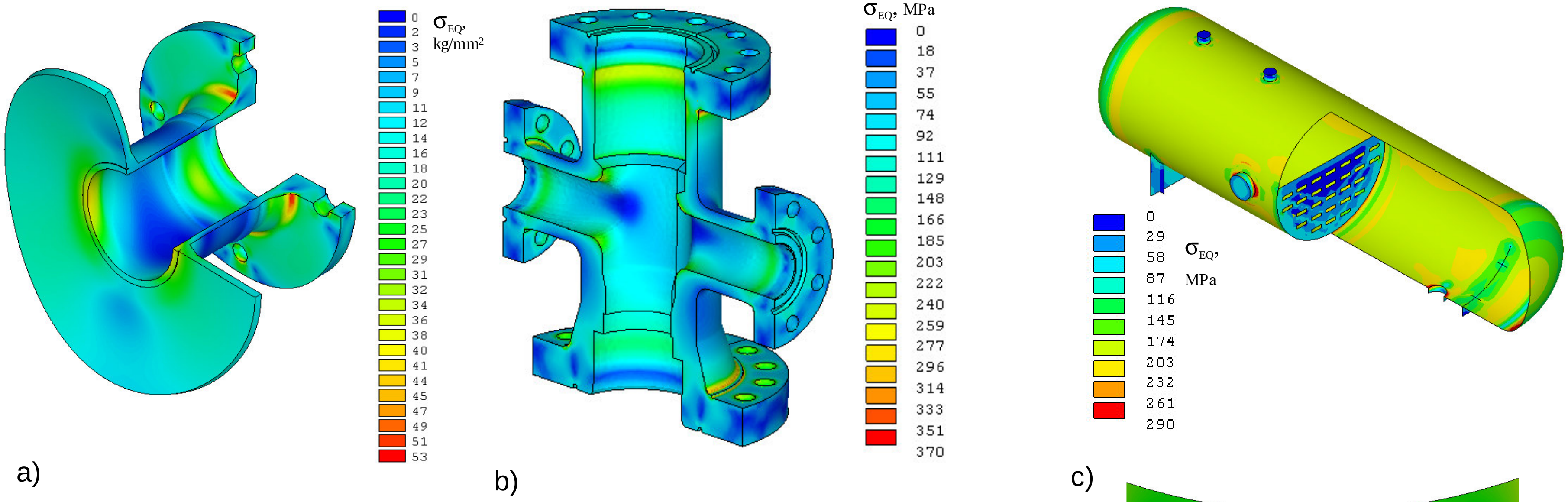
a) b) c) d)

Fig.38. Diagnostics and Repairs of Buried Pipelines:
a) carrying out electrometric surveys;
b) a copy of scanning pattern with plotted data on measurement results;
c) excavation of an active crude pipeline;
d) carrying out protective insulation repairs and application of polymer film cladding.

The Centre of Calculations and Experimental JSC «Tekhdiagnostica» is fully supplied with all necessary domestic and foreign (API 579, 580 and others) reference documentation, designing software (PVP-Design, COSMOS/M, LS-DYNA) and staffed with experienced personnel certified in strength calculations and having science degrees for research in the field of structural integrity.

Centre of Calculations and Experimental performs:

- ***check (rated) strength calculations according to domestic and foreign reference documentation with regard to criteria of all possible limiting conditions;***
- ***residual life calculations;***
- ***refined calculations with application of designing software and study of strength and remaining service life of high-loaded and damaged load-bearing structures;***
- ***optimisation of diagnostic and preventive activities.***



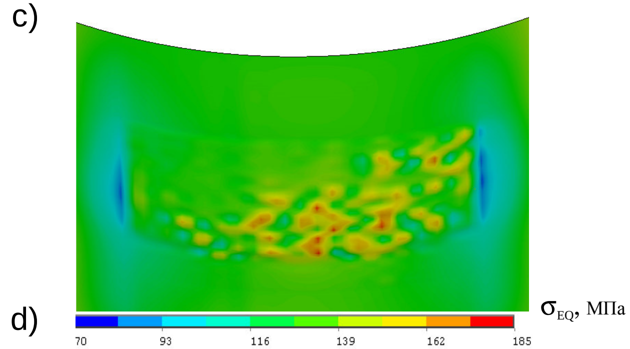
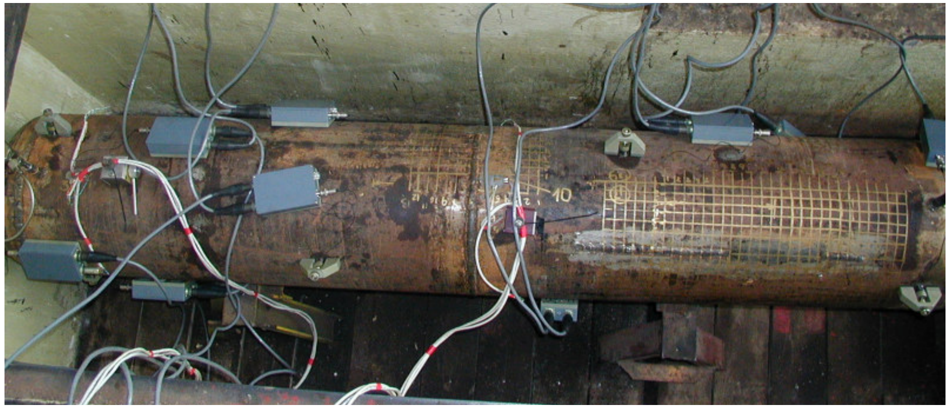


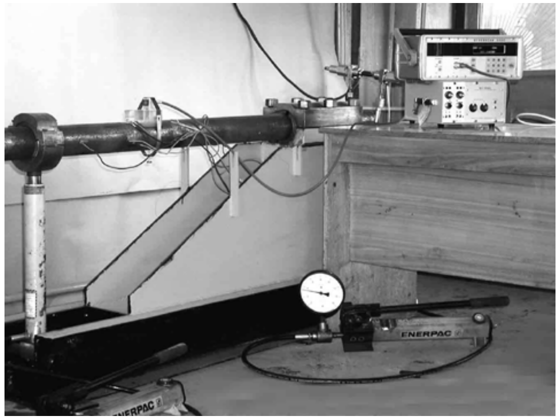
Fig.39. Examples of stress-strain analyses performed:
a) choke assembly with constructional lack of fusion;
b) tubing crosshead;
c) amine expansion tank;
d) vessel shell having a corrosive wear zone.

Our specialists have developed and successfully apply special testing stands including vessel models with made-up defects simulating incomplete weld penetration, corrosion pitting, wall thinning and other defects (see Figure 40).

a) experimental vessels having made-up defects in nipple socket welds



b) experimental vessel with made-up defects



c) testing stand for strained and deformed state examination

Fig.40. Test vessels

XII. The key advantages of applying the proposed system against well-known methods of sustaining of safe operating condition of process equipment lie in the use of failure risk level differentiated equipment components; simplicity and reliability of methods and techniques of identification of equipment component failure probability; systemic lowering of failure hazards and failure probability due to early defect detection, well-timed planning and initiation of preventive measures aimed to restore reliability and long-term operation of defective components; taking efficiency enhancement measures to preserve process equipment safe operating condition by distributing defective components throughout the failure risk levels.

CONCLUSIONS

1. Tekhdiagnostica developed new concepts, methods, techniques, parameters, criteria, safety control circuits, and systems of failure, accident and emergency prevention during operation of process equipment of gas processing and chemical treatment plants with regard to specific impacts of H_2S-bearing mediums enabling to predict process equipment failure probability within the range of acceptable values for forecasting periods.

2. Tekhdiagnostica substantiated and developed techniques and facilities which enable to enhance flaw detection reliability and expand controllability of equipment components by specific gas processing and chemical plant equipment defects and technical condition parameters.

3. Tekhdiagnostica prepared regulatory documents and database on process equipment conditions, and provided facilities for carrying out inspections and surveys of gas processing and chemical treatment plants equipment.

4. The above process equipment safety management system was tried out at Orenburg and Astrakhan gas processing plants. Safe equipment operating time and levels forecasted on the basis of inspection results have been confirmed in practice.

As the organisation of independent experts, Tekhdiagnostica is offering its services to inspect process equipment in gas, oil, petrochemical and other industries anytime, anywhere, in any volumes, and at a moderate price. Our goal is to lower accidental risks and failure hazards. Cooperation with our company will guarantee high quality of works at a minimal cost.

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