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PLANT ASSET MANAGEMENT RIMAP (RISK-BASED INSPECTION AND MAINTENANCE FOR EUROPEAN INDUSTRIES)[†] THE EUROPEAN APPROACH

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ABSTRACT

The paper presents an overview of the European project RIMAP (Risk-Based Inspection and Maintenance for European Industries) as well as a more detailed insight into its application for the power industry (RIMAP Power Workbook). RIMAP is partly financed by the European Commission for the "Growth Programme, Research Project"; Contract Number G1RD-CT-2001-03008.

INTRODUCTION

Globalization and increased competition are keywords that characterize the present development at a world wide market. A company's ability to recognize innovative concepts will be decisive for meeting the progressive demands at competitiveness.

Process-specific control and operation concepts in combination with a sufficient maintenance strategy significantly influence the economic efficiency of a plant in the same way as the quality of its products. Present-day plant management requires an integral approach to enable decision making, considering the interaction between different systems as well as between different phases during a life cycle with a focus on cost-effectiveness. Hence, it is strictly necessary to actively drive the plant's assets.

Adapted probabilistic reliability and risk assessment methods combined with the information extracted from generic and plant specific data as well as from structural reliability models yield to a solid foundation for decision making in a wide range of usage for asset management and maintenance optimization tasks. Special emphasis is given to the risk assessment, which is the foundation for making a decision. In this context the term "risk" is not limited to a risk concerning safety but also can be related to a risk concerning availability and ultimately money.

However, the current situation in Europe regarding inspection and maintenance activities in process and power plants is varying over a wide range. While in some European countries, like the UK, risk based approaches are in use and accepted by the industry and the authorities, in most of the other countries, e.g. Germany, the current practice toward safety related issues is still more or less time-based and prescriptive. This is due to the fact that in the European Union (EU)-member countries only the requirements for the construction and design of pressure vessel equipment is standardized (European Pressure Equipment Directive (PED), while all the legislation for in-service inspection is still with the national authorities (ISI-codes). The only requirement is that the national regulation must be adapted to the basics of the PED. Therefore, the main classification of pressure equipment in the PED with its influence on the construction and design requirements is adapted in several national ISI codes (e. g. German BetrSichV). In these cases, the expenditure for ISI is linked to the consequence classification in the PED. Whilst in the PED the word "risk" is avoided (the requirements are only consequence related) in the ISI codes one can often find implicit expression for risk if prescribed periods have to be extended or reduced. Here, it is often stated that efforts have to be adapted to the extent (=consequences) and the likelihood of what can happen, which is exactly the definition for "risk".

[†] RIMAP Consortium:

Det Norske Veritas AS	TNO Industrial Technology	ExxonMobil Chemical Ltd.	Bureau Veritas
Staatliche Materialprüfanstalt Stuttgart	VTT Industrial Systems	Energie Baden-Würtemberg AG	Corus Ltd.
Electricity Supply Board	Hydro Agri Sluiskil B.V.	The Dow Chem. Comp. N.V.	Siemens AG
TÜV Industrie Service, TÜV SÜD Group	Mitsui Babcock Energy Ltd.	Joint Research Centre of the EC	Solvay S.Y.

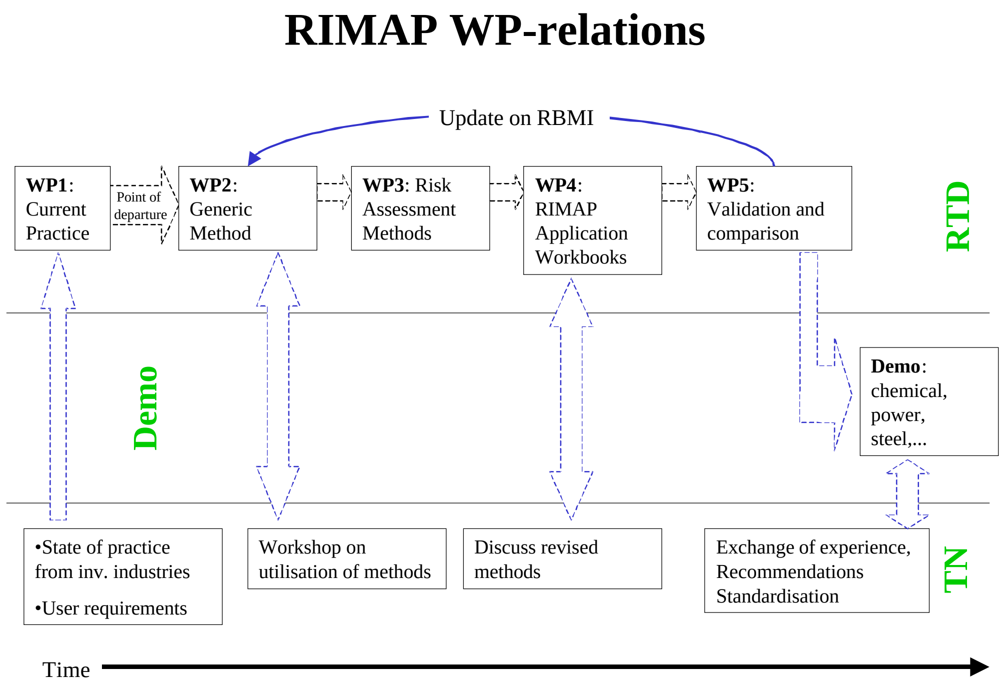

Fig. 1 Relationship between the RIMAP RTD WPs, the RIMAP Demo and the interaction with the RIMAP Thematic Network.

Due to the latter, risk-informed procedures are in principle suitable for getting acceptance in all EU-member countries and also in those countries having a more or less prescriptive regulation, risk-informed procedures for planning in-service activities are already on its way.

The main goal to be achieved is to find a European wide accepted method for risk-based inspection and maintenance and to embed available and existing methods, tools, standards, etc. To realize this issue, the European project RIMAP (Risk-Based Inspection and Maintenance Procedure for European Industry) was launched in 2001. In the following, the project will be described in general. After that a special insight will be given to the application within the power industry.

RIMAP (RISK-BASED INSPECTION AND MAINTENANCE FOR EUROPEAN INDUSTRIES)

Project Overview

Risk Based Inspection and Maintenance Procedures for European Industry (RIMAP) is a European project that shall develop a unified approach for making risk based decisions within inspection and maintenance. The focused industries are:

- Power,
- Petrochemical,
- Chemical and
- Steel.

The project is divided into three sub-projects:

- RTD (Research and Technology Development)
- DEMO (Demonstration for each industry sector)
- TN (Thematic Network)

The RIMAP RTD/DEMO/TN projects started in 2001. The RTD/DEMO projects will be completed in 2004, while the RIMAP TN will be completed in 2005.

The RIMAP RTD project is divided in 5 main technical work packages (WP), see Figure 1. The WP's are structured with a clearly defined interrelation in order to achieve an efficient execution of the project.

- WP1: Current practice within the involved industries.
- WP2: Development of a generic RBMI method, based on a multi-criteria decision process.
- WP3::Development of detailed risk assessment methods, damage models for participating industry sectors, the use of inspection data.
- WP4: Development of RIMAP application workbooks for each industry sector: guidelines for development of Risk Based Inspection and Maintenance plans.
- WP5: Validation of the RIMAP methodology.

The RIMAP DEMO project consists of 4 demonstration cases, one for each industry sector, to prove the applicability, while the RIMAP TN project accompanies the entire development by disseminating the information and results of the RTD and DEMO part to a wider community of companies to review what has been developed and to get an overall acceptance.

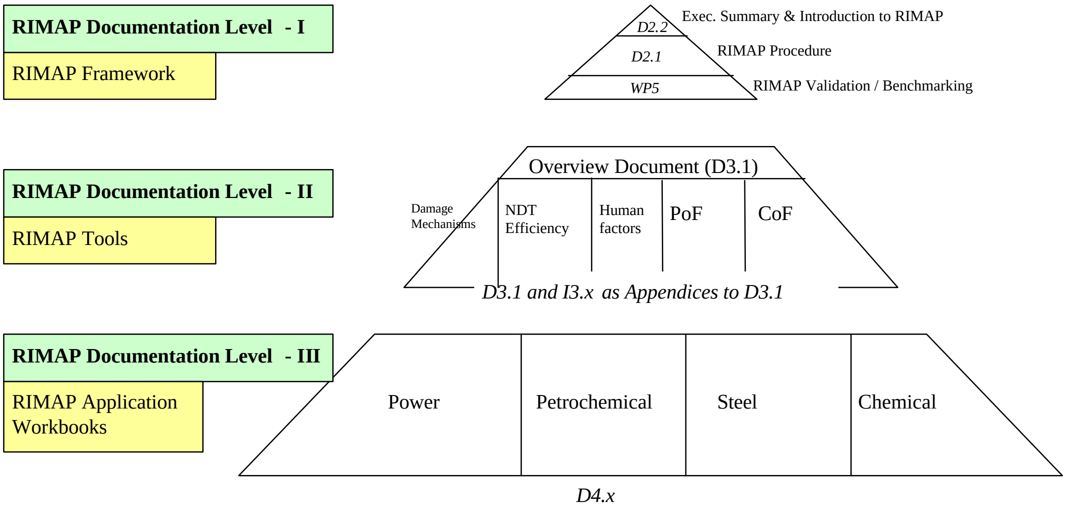

Fig. 2 RIMAP document hierarchy

The main deliverables from the RIMAP RTD project will be (the related documents can be depicted from Fig. 2):

- A method describing an unified approach to maintenance and inspection planning based on risk decision criteria and cost optimization.
- Guidelines for practical use, in the format of one "Workbook" for each industry sector.
- Spread knowledge between industry sectors.

The RIMAP method will be tested within 4 industry sectors in the RIMAP Demonstration project and, as such, it will be a major contribution to European standardization.

The project is currently completing WP4 and WP5 in addition to having started the industry specific demonstration projects.

The RIMAP Framework

In order to put the idea of risk based maintenance and inspection into action it is necessary to install proper procedures and tools within an adequate framework to ensure the required quality, transparency, and documentation.

The general RIMAP framework consists of the RIMAP working process (management related issues) and the RIMAP procedure (technical related issues), which are briefly described in the following:

RIMAP Work Process. To implement and manage a system for risk based inspection and maintenance management sets requirements to a plant's (maintenance) management system. Fig. 3 illustrates the work processes involved in implementing and managing RIMAP at a plant or facility.

RIMAP defines the working processes and provides requirements to the personnel that will execute the working processes. Implementation of RIMAP also requires an active management that focuses on the following issues:

- Management of change
- Operating procedures
- Safe work practices
- Pre-start-up reviews
- Emergency response and controls
- Investigation of incidents
- Training
- Quality assurance

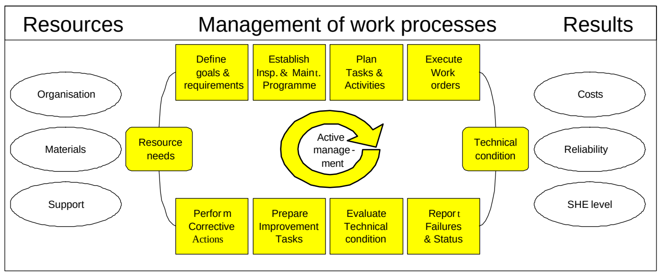

Fig. 3 RIMAP Work process

As risk based inspection and maintenance planning is a multidisciplinary task, it requires a team, where all necessary competencies are represented and expertise are available (e. g. EN 45004). Another important issue is the recurrent evaluation at a certain interval to assess all the modifications and new data available to make sure the entire process runs into a continuous loop.

RIMAP Procedure. In Fig. 4, the generic RIMAP procedure is shown. It is industry independent and applicable to different equipment types (static, safety systems, etc.).

The steps in the procedure are the same for different industrial sectors (chemical, petrochemical and power) and for different equipment types even if the techniques (e. g. tools for assessing probability or consequence of failure) may vary from one application to another.

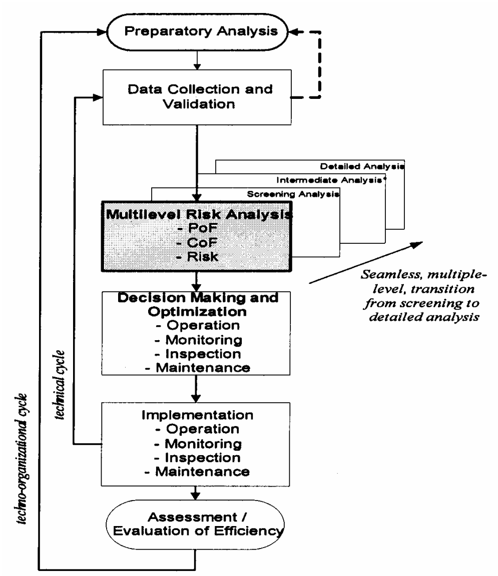

Fig. 4 RIMAP procedure

So, within the generic RIMAP procedure it is possible to meet the requirements of other already existing risk related programs like EN 1050 for machinery or IEC 61 508 for electrical safety systems. As shown in Fig. 4 above, the core of the procedure – the multilevel risk analyses includes a seamless transition from screening to detailed analysis. Here, it is obvious that for a certain level of risk a sufficient depth of the analysis is required.

The RIMAP description of Risk, PoF, CoF

The RIMAP project provides guidelines on how to perform risk based inspection and maintenance planning for all types of equipment: active components, static components, and safety critical equipment. The steps required to perform maintenance and inspection planning are similar for each type of equipment. The steps in the analysis are similar for all equipment classes:

Plant hierarchy: The plant hierarchy is a prerequisite for an efficient risk assessment and maintenance and inspection planning, since the plant is divided into manageable sections.

Failure mode: Assigning functions and sub functions to the physical items at the plant simplifies the identification of failure modes. The failure modes are then used to identify failure causes, root causes, and damage mechanisms.

Scenario development: RIMAP uses risk, the combination of probability and consequence of failure, to prioritize inspection and maintenance activities. The assessment of the probability and consequence of failure are combined in the bow-tie model, see Fig. 5. A scenario is damage mechanisms leading to a potential event with a consequence (safety, health, environment, or business).

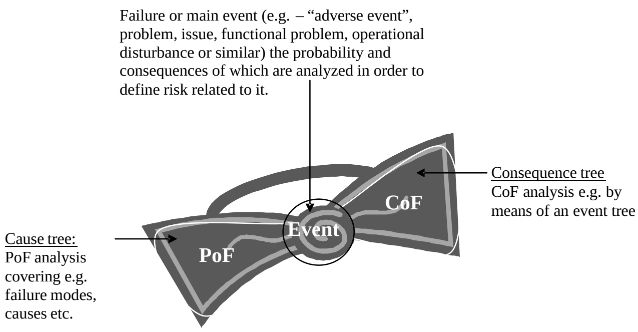

Fig. 5 The "Bow-tie-model"

Probability of failure (PoF): A number of methods for determining the probability of failure is discussed (expert judgement, rate models, statistical, physical models, etc.) The industry specific workbooks contain industry specific models.

Consequence of failure (CoF): Consequences of failure are divided into four categories. Safety – instant consequences on humans within or outside the plant's area. Health consequences – long term effects on humans within or outside the plant's area. Environmental consequences and business consequences of failure. Methods are provided for making this type of assessment.

Risk assessment: Risk is the combinations of the probability of failure and consequence of failure. The level of risk is compared to the company acceptance criteria regarding safety and environmental risk. For financial and cost consequences, a cost-benefit assessment is proposed. The cost is related to the mitigation cost. The benefit is the reduced risk versus the mitigation.

Mitigating activities and risk reduction: Based on the risk assessment (safety, health, environment, business) mitigating activities are proposed for the high-risk items. Mitigation activities can be maintenance/inspection, redesign, operational constrains depending on the actual case.

Methods for PoF assessment. RIMAP does not recommend particular methods for PoF assessment although the industry specific workbooks describe some methods for PoF assessment. RIMAP recommends that the level of detailing is adapted to the case and the risks involved. This means that in some cases expert judgement by domain experts can be considered as good as more advanced calculations. The project stresses the need for good information to base the assessment on.

The PoF assessment enters into the analysis in different ways for the static equipment, safety critical components and rotating equipment:

- Static equipment: For trendable degradation mechanisms, the acceptable risk is combined with the consequence of failure to determine a PoF limit. The PoF limit is combined with the damage rate to obtain a maximum time to inspection.
- Safety critical equipment: For safety critical equipment the risk assessment is used to determine a requirement on availability. This limit is then used to determine maintenance strategies that meet the requirements, mostly related to testing to find hidden failures.
- Rotating Equipment: The PoF assessment, given a certain maintenance program, is combined with the CoF assessment to obtain a risk for the given maintenance program. The level of maintenance is then chosen such that 1. SHE requirements and legislation is satisfied and 2. maintenance program is cost optimal within the boundaries that 1. define.

For both static equipment and safety critical equipment more frequent inspection or maintenance may be proposed if this is more cost effective.

CoF assessment. A set of requirements to CoF assessments have been formulated. Complying with the requirements implies that the RIMAP procedure has been followed. Methods for assessing the safety, health, environmental, and business consequences of failure have also been given. The consequence assessment applies to all equipment types (static, rotating, instrumented protection functions) and to all industry sectors represented in the project. The methods are easily extended to other industry sectors.

The consequence assessment is based on a certain scenario. RIMAP distinguishes between two types of scenario:

- Worst case scenario: Combine a given root cause/damage mechanism with the most serious/severe consequence that the given root cause/damage mechanism may lead to, e.g. loss of all fluid within the segmentation area, ignition, etc.
- Expected scenario. Combine the root cause/damage mechanism with the expected or typical consequence that the given root cause/damage mechanism will lead to.

RIMAP recommends use of the expected scenario in analyses. This is dependent on the degradation mechanism expressed in the scenario definition. It is essential that the choice of approach is made before the analysis starts and that the same method is used consistently throughout the analysis. If a consistent scenario is not used, the choice of risks mitigated will be affected, which may lead to a sub-optimal maintenance and inspection plan.

THE RIMAP APPLICATION WORKBOOK FOR POWER PLANTS

The current RIMAP Application Workbook for Power plants includes two main parts on the methodology application and appendices on supporting information.

Part I

Detailed description on how to set up and perform risk analysis. This section outlines the standard format, preparatory analysis, data collection and validation, multilevel risk analysis and decision making, assessment of inspection techniques, implementation of plans, and evaluation of the overall process.

In the damage mechanism section, the essential systematic aspects of damage mechanisms, applicable to power plant related components, are covered, including where and how to look for damage, as well as analysis and prediction methods of damage development.

On plant hierarchy, a recommendation for a standard hierarchy is given (see Table 1) with examples for possible damage related issues. See Table 2, where recommendations are given on a component level using the number and quality of the "stars" to quantify the applicability of a certain deterioration mechanism.

Water systems (G, L)
Feedwater/boiler water systems (G, L)
Feedwater treatment
Feedwater treatment (GA, GB, GC)
Condensate treatment
Condensate polishing (LD)
Boiler water transport
Feedwater pumps (LAC)
Condensate pumps (LCB)
Feedwater piping (LAB)
Feedwater tank, deaerator (LAA)
Feedwater heaters (LAD)
HP feedwater heaters
LP feedwater heaters

Table 1 Extract: Recommendation for the plant hierarchy

The risk analysis section outlines applicable procedures, and PoF/ CoF evaluating methods. The section on risk consideration deals with reduction and mitigation of risk with links to maintenance and inspection techniques.

Part II

System / Subsystem / Component data on item by item basis. The system and component related considerations are listed and default information is given item per item.

The main systems and components that are currently covered to varying extent include:

- Fuel supply and waste disposal system
- Boilers for conventional steam generation
- Steam systems (piping)
- Steam turbines
- Gas turbines
- (electric) generators
- electric distribution

Under these headings, different subsystems and components are considered from the point of view of general features and operating conditions, typical damage mechanisms and failure modes, basic default PoF and CoF data (with references), description of typical preventive and corrective actions, and suggested rating scales on PoF and CoF factors for specific problems on a given component type.

Damage Mechanisms / Plant Hierarchy	MATERIAL DAMAGE RELATED PROBLEMS														DISTURBANCES / D… PROBLEMS (not related to…			
	I. Corrosion/erosion/environment related damage, equating or leading to:								II. Mechanical or thermo-mechanical loads related, leading to:					III. Unknown structural damage mechanisms	IV. Fouling / deposits	V. Vibration, improper dimensioning of clearances	VI. Sabotage, terrorist attacks and man made disturbance	VII. …
	Volumetric loss of material on surface		Cracking (on surface, mainly)			Material weakening and / or embrittlement			Wear	Strain dimensional changes	Micro void formation	Micro cracking, cracking	Fracture					
	I.A1 General corrosion	I.A2 localized corrosion	I.B1 stress corrosion	I.B2 hydrogen damage	I.B3 Corrosion fatigue	I.C1 thermal degradation	I.C2 carburization	I.C3 embrittlement (strain)	II.A sliding wear, cavit wear	II.B overloading, creep	II.C creep, creep-fatigue	II.D fatigue (HCH, LCF)	II.E overloading, brittle f.					
Conventional steam generation (VTT)																		
Boilers																		
Boiler tubes																		
▪ *Economiser tubing*	★	☆			☆				★			★			☆			
▪ *Risers/down comers*	☆				☆							☆						
▪ *Waterwall tubing*	★★★	☆☆		☆	☆☆				★★★						★★★			
▪ *Superheater /reheater tubing*	☆☆	☆				☆☆			★★	★★★		☆			☆			
▪ *Boiler tube attachments*	☆				☆							☆☆						
Headers and drums																		
▪ *Steam drums*	☆	☆			☆							★★						
▪ *Economiser*	☆	☆			☆							★★						

Table 2 Extract: Plant hierarchy vs. "typical problems"

DEMO APPLICATION

The full scale application of the RIMAP Power Workbook took place at a South German coal fired 760MWe power plant, in operation since 1987. The demo has the following main objectives:

- to demonstrate the applicability and usefulness of the RIMAP methodology on several practical cases.
- to demonstrate several economic advantages
- to demonstrate the benefits of standardization
- to give input and feedback to further development of the methodology and standards for power related issues.

The assessment presented focuses on parts of the boiler, the main steam piping, and the hot reheat piping (overall 64 components).

Risk analysis was done on three levels: "screening", "intermediate" analysis and "detailed" analysis.

On the level of screening, only the general statistical data and the results of on-line monitoring were taken into account. For this purpose, the existing measurement systems (measuring pressure, temperature and temperature difference at the calculation points) and the existing fatigue monitoring system were used. For the purpose of risk analysis, the algorithm was extended for the probabilistic analysis (Monte Carlo simulation).

On the level of intermediate analysis, inspection results (replica) were introduced and probabilistic assessment of replica findings was done.

For the detailed level, the analysis was extended by means of probabilistic high-temperature fracture mechanics and the fatigue-creep crack growth analysis. In addition to the analysis of recorded data, the detailed analysis also included "what-if" analysis for different assumed load cases and it was accompanied by the corresponding non-destructive testing on a model (establishing of the minimum detectable nozzle corner crack for the most critical component.

The principle is shown in Fig. 6. For detected cracks the real dimensions of which can reach critical crack size, i.e. can be larger than the measured ones (here one 25 mm crack only) are to be assessed. As well as undetected cracks, among which a crack of a critical size may appear.

The results of the work clearly show the benefits of the proposed method for concentration on “critical items”: Out of the 64 monitored components taken for screening analysis (see Fig. 7), 6 were selected for intermediate analysis and only 1 for the detailed assessment.

In addition overall level of risk was managed all the time and the costs and benefits of risk based approach were made visible, transparent and measurable. Characteristic results are shown in Fig. 8.

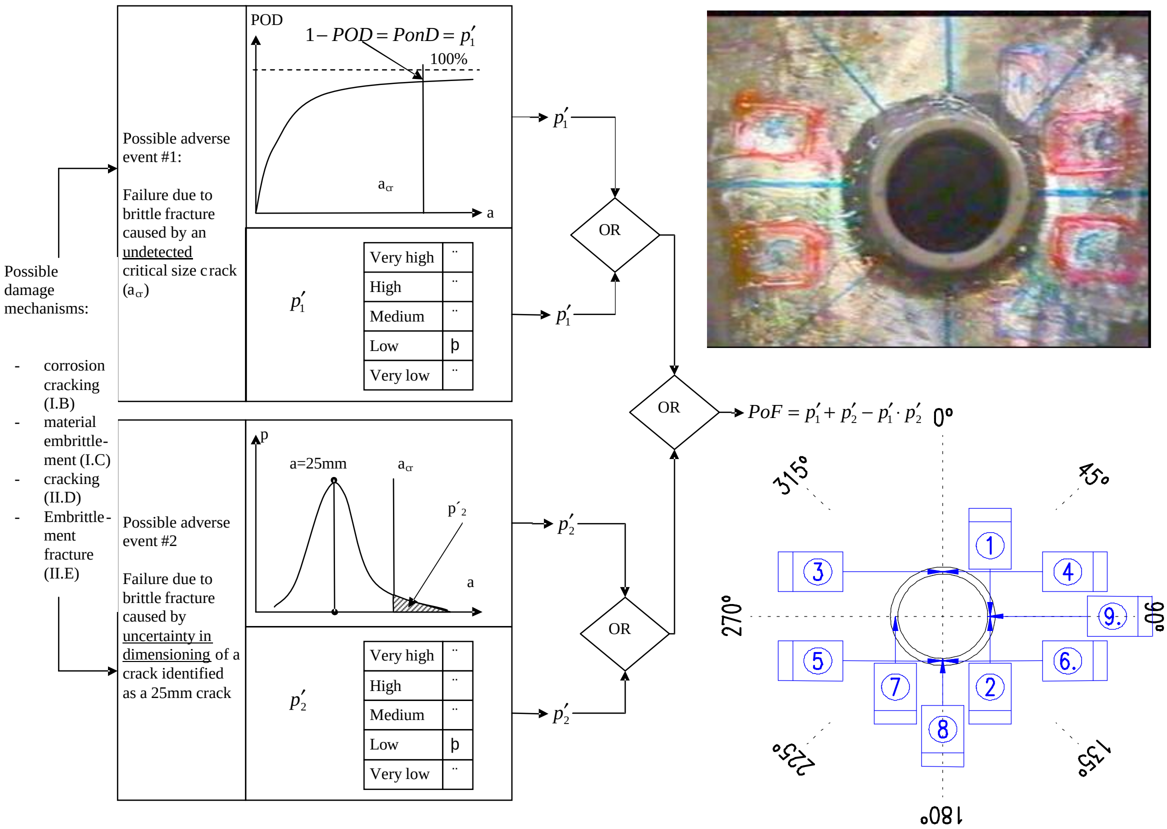

Fig. 6 Definition of PoF for the case of a structural failure and its main root cause

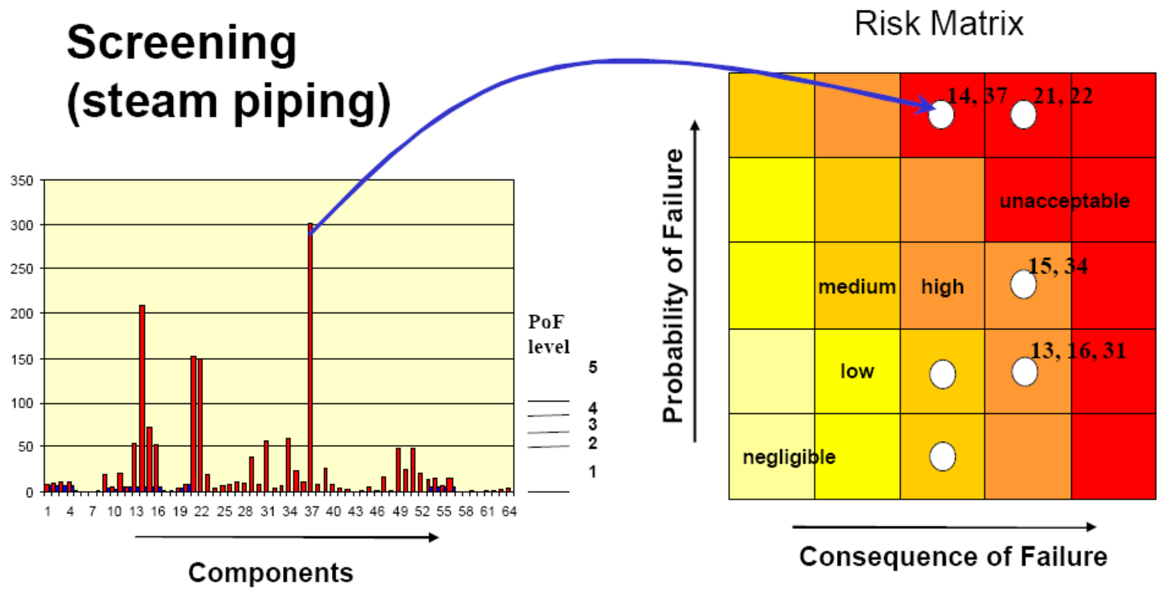

Fig. 7 Determination of critical components (screening analysis)

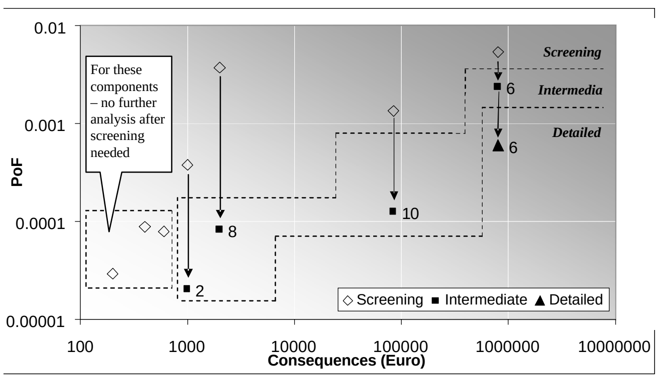

Fig. 8 Overall results (screening, intermediate, detailed)

CONCLUSION

European practices for risk-based decision making are under development to create a guideline and applicable tools for practical use. The current project RIMAP, involving more than 40 companies promises to deliver a consolidated European risk-based practice.

The application from power plants presented here and the other industries covered, will demonstrate the applicability and principle acceptance of the procedures and tools and lead to an acceptance of the methodology throughout Europe.

Detailed information can be gathered on the project's websites, (see References).

NOMENCLATURE

EU	European Union
CoF	Consequence of failure
D	Deliverable
ISI	In-service inspection
NDT	Non-destructive testing
PED	European Pressure Equipment Directive 97/23
PoD	Probability of detection
PoF	Probability of failure
RIMAP	Risk Based Inspection and Maintenance for European Industries
RTD	Research and Technical Development
TN	Thematic Network
WP	Work package

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REFERENCES

More information and references to special aspects are given at

RIMAP RTD or RIMAP Demo project:
http://research.dnv.com/rimap
RIMAP TN:
http://www.mpa-lifetech.de/rimap