MPA STUTTGART

Stuttgart, Germany, October 5, 2001

EPERC Workshop on

In-Service Inspection and Life Management of Pressure Equipment

- EPERC Technical Task Forces 3, 5 and 7 -

organized in the framework of and in conjunction with 27th MPA Seminar

Coordinator

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R. Koers, Chairman of EPERC-TTF7, Shell, The Netherlands

J. H. Rantala, Co-chairman of EPERC-TTF5, JRC Petten, Petten, The Netherlands

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Supporting organizations:

EPERC

CEC - JRC Petten, The Netherlands

MPA Stuttgart, Germany

Proceedings

Editors:

A. Jovanovic – MPA Stuttgart

P. Lejuste, P. Castello, R. Houghton – EC-DG JRC/IE

Summary

The workshop is envisaged primarily as an occasion for the members of EPERC's Technical Task Forces 3, 5 and 7 (EPERC - European Pressure Equipment Research Council) to discuss the technical issues relevant to their scope of work more in detail. Hence, the members of the above TTFs are the main intended participants of the workshop, it has been envisaged as an opportunity for them to exchange information and coordinate their work. In addition, the workshop should provide a possibility to external participants, otherwise not participating in the work of EPERC TTFs, to have an insight into the work of EPERC-TTFs.

The emphasis of the workshop is on inspection and life management, hence the engineers dealing with materials, design, remaining life assessment, structural analysis, safety analysis, plant management, failure cases, repair welding and related domains are expected to benefit from the workshop

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Session I
Introduction into EPERC and its activities in the area of inspection and life management

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1.2. *G. Baylac*: EPERC and its relation to PED, with special emphasis on inspections at manufacturing stage and the in-service ones – In-service inspection and PED

1.1. S. Szusdziara:
Overview of EPERC, its TTFs, membership and objectives

- *Abstract*
- *Presentation*

OVERVIEW OF EPERC, ITS TTFs, MEMBERSHIP AND OBJECTIVES

S. Szusdziara
Vice-Chairman of EPERC

Abstract

The initial idea of creating a European Pressure Equipment Research Council as partner of the American Pressure Vessel Research Council (PVRC) was discussed with the European Commission in early 1987. The realisation of the project started in Düsseldorf after the International Conference on Pressure Vessel Technology (ICPVT) 1993. Two years later the European Pressure Equipment Research Council (EPERC) was created in Paris by assignment of the statues of EPERC by about twenty individuals.

The first Steering Committee was held in February 1996 where the main structure of EPERC was decided. After a survey to establish the priority R&D needs of the European PE Industry in 1997 Technical Task Forces (TTF) were created for the identified priority R&D areas. These were clustered into the projects design, materials & joining, testing & inspection and operating & maintenance.

Today the voting members of EPERC represent about 210 organisations in the countries of the European Economic Area, Switzerland and four EU candidate countries.

EPERC

EPERC

European Pressure Equipment Research Council

Workshop on
In-Service Inspection and Life Management of Pressure Equipment
Stuttgart, Germany, October 5, 2001

Overview of EPERC, its TTFs, membership and objectives

Sieghart Szusdziara
Fachverband Dampfkessel., Behalter-und Rohrleitungsbau (FDBR) e.V., Germany

EPERC

Initial Idea

The idea of creating a European Pressure Equipment Research Council (EPERC) as partner to the American Pressure Vessel Research Council (PVRC) was born by

- *Roy Nichols, UK*
- *Roland Roche, FR*
- *Karl Kußmaul, DE*

and discussed with the European Commission in early 1987

EPERC

Realisation

The idea was picked up by

- *G. Baylac, FR*
- *B.J. Darlaston, UK*
- *S. Szusdziara, DE*

In 1993 during the ICPVT (International Conference on Pressure Vessel Technology) in Düsseldorf.

Following up a concept for a European Pressure Equipment Research Council was developed and a club-type agreement was drafted.

EPERC

Creation

The European Pressure Equipment Research Council (EPERC) was created by assignment of the statutes of EPERC by about twenty individuals and European organisations during the ICPVT/AFIAP Conference in Paris on October 1995.

The first Steering Committee was held in February 1996 where
- the main structure of EPERC was decided and
- officers for the management of the organisation were elected.

EPERC

Creation

Today

- *Voting members are from about 210 organisations in the 15 EEA (European Economic Area) countries and Switzerland*
- *Non-voting members are from 4 EU candidate countries*

EPERC

Objectives

- *Establish a European Network in support of the Non-Nuclear Pressure Equipment Industry*
- *Establish R&D priorities for this industry sector*
- *Identify and stimulate funding of these R&D priorities*
- *Return of results to European PE industry by means of improved technology transfer activities.*

EPERC

Added Value

- *Draws together European expertise*
- *Provides a unified representation and improved image of the European PE industry*
- *Representation facilitates effective promotional & advisory roles to the EC on behalf of the PE industry*
- *Identifies common industrial needs*
- *Removes redundancy through networking of effort*
- *Leads to targeted & cost effective R&D*
- *Benefits industry through input to standardisation activities, & information transfer to small and medium industries.*

EPERC

Administrative Task Groups

TG1 - Business management of EPERC

TG2 - Current European & International R&D activities

TG3 - R&D needs of industry

TG4 - Support of European policy and CEN

TG5 - Technology transfer

EPERC

R&D Needs of Industry

- *Survey to establish the priority R&D needs of the European PE Industry (1997)*
  - *Questionnaire prepared & distributed*
  - *Evaluation of replies*
  - *Proposal of priority research needs*
- *Survey updating foreseen as necessary*

EPERC

European Policy & CEN

- *Develop links with key EC DGs*
- *Establish supporting role to the European Commission*
- *Support to CEN and CEN-STAR standardisation activities*
- *Identify funding for PE R&D within Framework Programme*

EPERC

Technology Transfer

- *Dissemination of research results to Industry*
  - *Newsletter & EPERC Bulletins*
  - *WWW Internet Site for the benefit of the European PE community*
- *Educational role*
  - *Journals, Seminars, Courses*

EPERC

Links with Organisations

- *EC DGs*
- *CEN, CEN/STAR and CEN TCs*
- *PVRC & JPVRC*
- *Industrial Trade Associations*
- *National Standards Bodies*

EPERC

Main EPERC Officials

Chairman
L. Valibus

Vice Chairman
B.J. Darlaston

Vice Chairman
S. Szusdziara

Technical Advisor
G. Baylac

Secretary
J.B. Veyret

EPERC

Steering Committee Members

Austria	J.L. Zeman
Belgium	W. Provost
CEOC	M. Völzow
Denmark	V. Andreasen
Finland	K. Rahka
France	C. Loth
Germany	S. Szuszdiara
Greece	V.L. Tsantzalou
Italy	A. Leni
Netherlands	J. Kops
Spain	W. Azpiazu
Sweden	L. Dahlberg
Switzerland	R. Kieselbach
UK	B.J. Darlaston

EPERC

Technical Task Forces

TTF1 - Fatigue design

TTF2 - High strength steel for PE thickness reduction

TTF3 - Harmonisation of inspection Programming in Europe

TTF4 - Sealing Technology

TTF5 - Integrity Assessment during Operation

TTF6 - Tanks for alternative fuels

TTF7 – Hydrogen Damage

EPERC

Projects

Design

- *Fatigue Design (TTF1)*
- *Sealing Technology (TTF4)*

Materials and Joining

- *High Strength Steels (TTF 2)*
- *Alternative Fuel Tanks (TTF 6)*
- *Hydrogen Damage (TTF 7)*

Testing and Inspection

- *Harmonisation of Inspection (TTF3)*

Operation and Maintenance

- *Integrity Assessment during Operation (TTF5)*

September 2001 15

1.2. G. Baylac
In-service inspection of pressure equipment and PED

- *Abstract*
- *Presentation*

IN-SERVICE INSPECTION OF PRESSURE EQUIPMENT AND PED.

G. Baylac
EPERC Technical Advisor

Abstract

The pressure equipment Directive applies to the design, manufacturing and conformity assessment of pressure vessels and assemblies. It applies up to placing on the market and putting into service. The link between PED and in-service inspection (ISI) is not obvious. In-service regulations are under the control of the Member States and may differ from one country to another. France has chosen to publish new regulations who draw the maximum from the PED.

The presentation will be devoted to the description of the French decree dated December 1999 and of the Ministerial Order of application. Reference to the Directive gives to these regulations an objective context, opens to more responsibility from the user and invites EPERC to prepare recommendations for in-service inspection.

IN-SERVICE INSPECTION OF PRESSURE EQUIPMENT AND PED

GUY BAYLAC

Introduction 1

- The pressure equipment Directive (97/23/CE of 29 May 1997) applies to:
  - Pressure equipment
  - Assemblies
- PED applies up to:
  - Placing on the market
  - Or putting into service

Introduction 2

- PED aims
  - at removing barriers to trade
  - a high level of safety
- PED is of total application from 30 May 2002
- In-service inspection regulations on the control of the Member States

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Introduction 3

- Link between in-service inspection (ISI) and PED not obvious
- However there is a good example of good connection between PED and ISI: the recent French Legislation
  - Decree 13 December 1999
  - Ministerial Order 15 March 2000

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Topics

- Putting into service of equipment
- Periodic inspections
- Periodic requalifications
- Repairs

Decree : Article 17

- Framework document : announces publication of the Ministerial Order
- Proceeds by ESR's
  - User shall keep documentation
  - User responsible for maintenance
  - Equipment installed to allow maintenance and inspection
  - Requirements for assemblies shall meet ESR's
  - User shall define conditions of use

Decree : Article 18

- Declaration of putting in service
- Inspection of putting into service
- Periodic requalification
- Inspection after repair

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Ministerial Order

- Field of application based on the classification of the Directive (vessels, steam generators, safety accessories, …)
- Approved user inspectorate
- Surveillance by DRIRE

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Installation

- Reference to Annex I of the Directive (vessels, steam generators, fast closures, …)
- Permanent joining
- Technical documentation

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Periodical inspection

- 12 Months for cylinders for diving
- 18 Months steam generators and fast closures
- 40 Months other PE
- Who does what ?

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Periodic requalification

- Equipment and accesssories
- Time interval specified
- Surveillance by DRIRE or delegation
- Flexibility of time interval for approved User inspectorates

REPAIRS

- Requirements applicable to new equipment
- Inspection of DRIRE

Conclusion

- Need for developing rules for RBI
- Document of definitions and principles
- Examples of application
- Effort on management of Data Bases

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Session II
TTF3 – Inspections, Inspection Harmonization, Maintenance

Terms of reference of TTF3

TERMS OF REFERENCE OF TTF3:
Harmonisation of Inspection & Maintenance

Overall objective of TTF3 is development of harmonised European recommended practices for inspection and maintenance, based on state-of-the-art diagnostics (e.g. inspection, monitoring, promotion of innovative cost-effective, non-intrusive and process non-disruptive methods, etc.). The ultimate goal of such practices is to improve the availability of plant components, especially of the critical pressurised non-inspection driven ones. This goal shall be achieved in the framework of a reliability focused, risk-informed and risk-aware engineering approach, considering both availability and safety aspects.

Major items on the agenda of TTF3 are:

- Surveys on the NDE inspections within the European pressure equipment industry
- European inspection qualification methodology for the pressure equipment industry
- Development of a framework for RBI/RBLM (Risk-based Inspection, Risk-based Life Management)
- Promotion and consolidation of new methods for cost-effective and reliable inspections of pressurised equipment
- Quantification of the reliability of the information to be given by inspection and monitoring techniques
- Collaboration with other TTFs and other organisations.

The items are covered by the following respective activities (finished/on-going/planned) and the corresponding deliverables:

1	Extensive inquiries in European pressure equipment industry (use of NDE methods, qualification, manufacturing inspection requirements, harmonisation, RBI, RBI*/RBLM**) – reports published and results disseminated.
2	Extensive reports summarising recommendations on inspection harmonisation (e.g. ENIQ) discussed in workshops and presented Europe-wide.
3	Successful promotion RBI/RBLM in inspection and maintenance, involving currently 17 European companies in its RTD and Demonstration part, 34 partners in its network part and a constantly increasing of partners taking part in the project at their own costs as observers.
4	Planned promotion of "Reliability of NDE for pressurised equipment", with the preparatory actions co-ordinated by TTF3.
5	Joint meeting with e.g. TTF5, links to CEN (e.g. CEN TC 54).

* RBI : Risk-Based Inspection
** RBLM : Risk-Based Life Management

2.1. A. Jovanovic, A. Eriksson
Overview of TTF3 activities

- *Presentation*

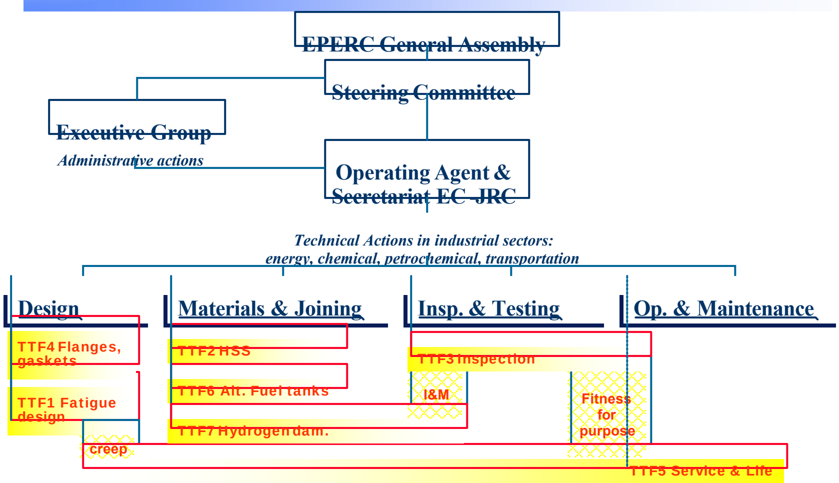
Overview of TTF3 activities (Technical Task Force No. 3): Inspection and Maintenance

A. Jovanovic, A. Eriksson

EPERC Workshop, October 5, 2001

Stuttgart, Germany

TTF interaction...



TTF3 – Numbers…

One of the first TTF's,…

- **Mailing list:** ~ 450
- **Membership list:** ~ 70
  (~ 2/3 industry, ~ 1/3 non-industry)
- **Participation, meetings:** ~ 15-40
  (currently: ~ 1/3 industry, ~ 2/3 non-industry!)
- **JRC-cochairman** A. Eriksson
- **Vice chairperson** Ms. Müller (BAM Germany)
- **Chairman** Jovanovic (MPA Stuttgart, Germany)

TTF3 – Terms of Reference

Keywords (emphasis):

- Opportunity driven inspection
- Non-intrusive
- Use of monitoring
- Global use of all information available
- Quantification of reliability
- Inspection only where and when needed
- "Translation" of all information into defect acceptance
- Integration of all information and management supported by informatics tools

TTF3 – Terms of Reference

Keywords of actions, practice and projects:

- Risk issue, in view (also) of
  - Reliability
  - Availability
  - safety
- Inspection capability evaluation
  - Blind tests
  - Internationalization of national results
  - Parametric studies…
  - …
- Qualification of inspection procedures and equipment
- Development of quality programs
- Information based management schemes
- …

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TTF3 Terms of reference

TTF3: Harmonisation of Inspection & Maintenance

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The items are covered by the following respective activities (finished/on-going/planned) and the corresponding deliverables:

1	Extensive inquiries in European pressure equipment industry (use of NDE methods, qualification, manufacturing inspection requirements, harmonization, RBI, RBI/RBLM) – reports published and results disseminated
2	Extensive reports summarizing recommendations on inspection harmonization (e.g. ENIQ) discussed in workshops and presented Europe-wide
3	Successful promotion of the European project RIMAP on RBI/RBLM in inspection and maintenance, involving currently 17 European companies in its RTD and Demonstration part, 34 partners in its network part and a constantly increasing of partners taking part in the project at their own costs as observers.
4	Successful promotion of the dedicated call on TOFD with several proposals submitted for the deadline of March 15, 2001
5	Planned promotion of the new dedicated call on "Reliability of NDE for pressurized equipment", with the preparatory actions coordinated by TTF3
6	Joint meeting with e.g. TTF5, links to CEN (e.g. CEN TC 54)

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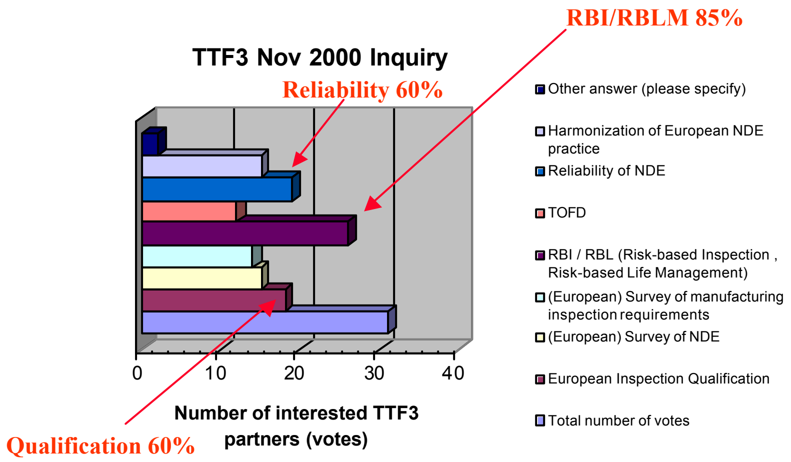
TTF3 – Activities on “one page”

- **“Past”**
  - **Much of the work linked to nuclear, to the CEC work, less to non-nuclear industry**
    - **EXAMPLE: Inspection Qualification (ENIQ)**
- **“Present”**
  - **Participation of the non-nuclear industry**
  - **Link to CEN:**
    - **TTF3**: **Recommendations** vs. **CEN**: **Standardization**
    - Meeting held – no problems present at the moment…Further contacts and joint actions planned (e.g. Joint Seminar on Risk in 2002)
  - **Reporting to TTF members about (or involving them as e.g. observers in) on-going RTD projects which they have promoted**
    - **EXAMPLE: RIMAP project**
    - **EXAMPLE: TOFD project**
  - **Collaboration with other TTF’s**
    - **EXAMPLE: EPERC Workshop in Stuttgart, Oct. 5, 2001**
- **“Future”**
  - **Identify and quantify the needs for future projects**
    - **EXAMPLE: Dedcated call “Reliability of NDT for RBI/RBLM”**

RISK-BASED INSPECTION and RISK-BASED LIFE MANAGEMENT

Future needs:
Results of the TTF3 inquiry November 2000



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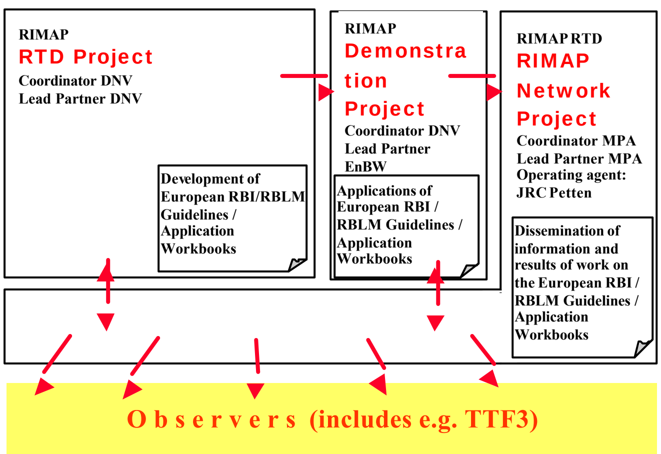
RIMAP Project(s)



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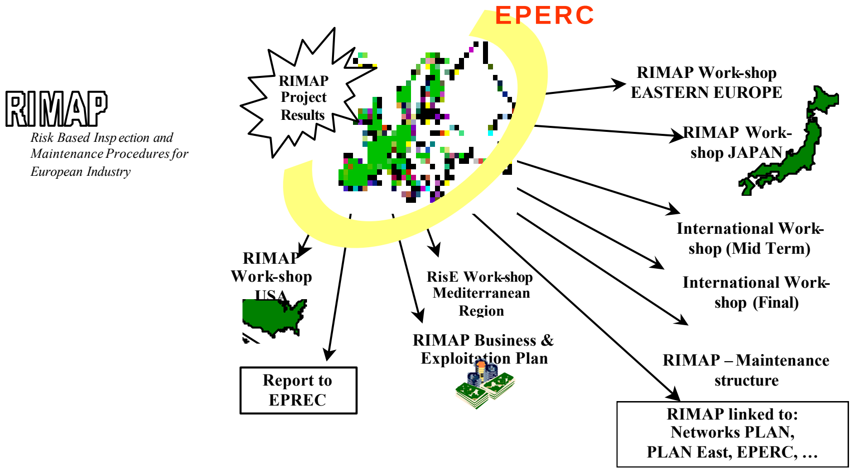
EPERC support for RIMAP dissemination



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TOFD

- Dedicated call in October 2000
  - TTF3 involved in its preparation of the call
  - TTF3 has influenced preparation of the proposal
  - TTF3 informed about the proposal
  - TTF3 will be invited to observe the development of the project (approved!) and evaluate some of the results
  - TTF3 (EPERC) will be used for dissemination of results

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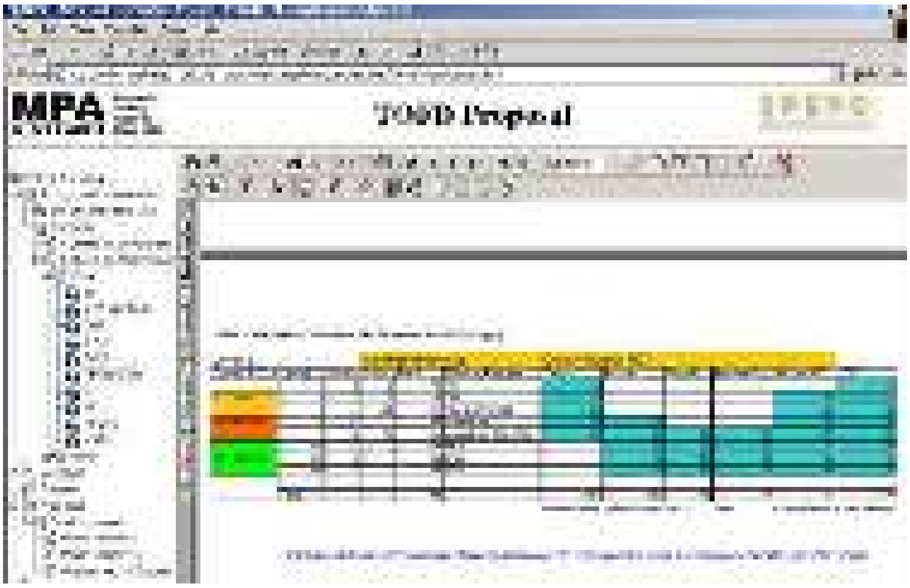
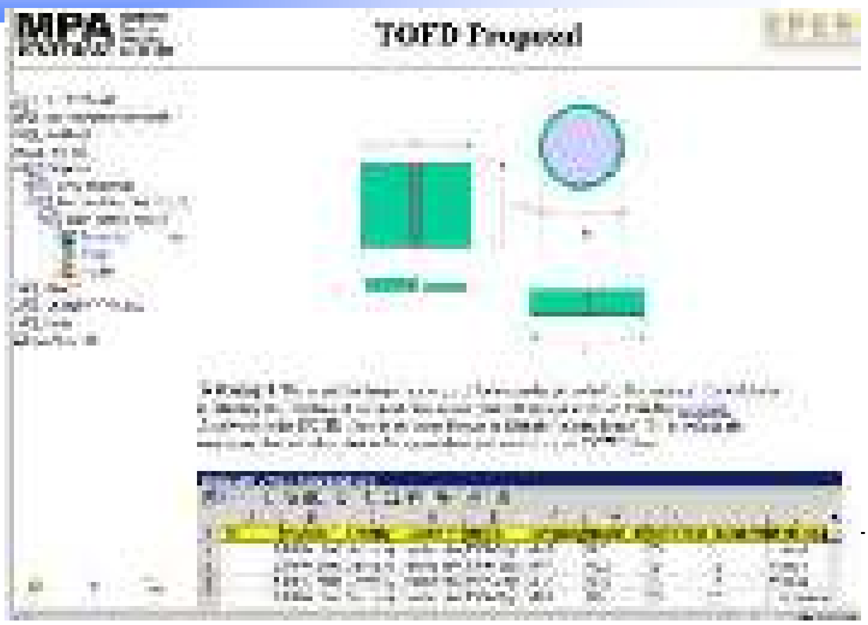
Next Future: TOFD



Next Future: TOFD

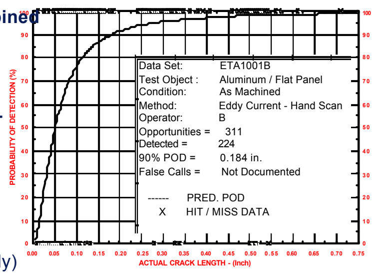


Quantitative reliability of NDT for improved/optimized RBI/RBLM of pressure equipment (pressure vessels and piping)

Future 6th FP: RBI/RBLM-oriented Reliability of NDE

- **Initiators from TTF3: MPA, BAM, AEA, …**
- **Desired features**
  - **Provide (quantitative) input for RBI/RBLM**
  - **Provide "Rummel-like"/Nordtest collections of POD/PFC curves for EPERC relevant applications (materials, types of components, method applied, inspectors qualifications, …)**
  - **Place the issue in the right concept of combined concept including both fitness for purpose analysis and RBI (Note: Fitness for purpose + RBI + + NDE-Reliability … ≈ RBLM or …API 579 + API 580 + API 581 + NDE-Reliability + …)**
  - **Reliability as a function of 3 factors**
    - Intrinsic capability
    - Application parameters
    - Human factors

    … the factors must MODELLED and (possibly) QAUNTIFIED!



Background

- "Rummel" is
  - US-oriented
  - aerospace oriented (not pressure equipment oriented)
  - …
- Other studies, including Nordtest
  - mostly old, not corresponding to performance of NDT today
  - mostly POD-only
  - some methods completely "forgotten": e.g. replica
- PISC
  - was nuclear
  - has not produced a standard procedure
  - was UT-oriented
  - …
- ENIQ, NESC, PANI, …
  - nuclear, UK, …
- RIMAP, NURBIM
  - need data on reliability of NDT, but do not have them
  - will be improvising in the area…
- …

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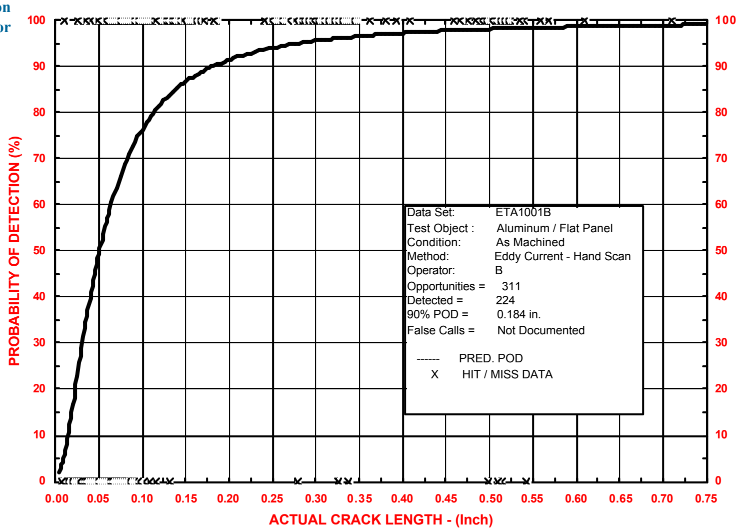
Where the probabilities come from … NDE

Stress corrosion ET Example for POD and FCP data (Rummel 1997)



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MPA solution - RBLM ...

On-going

- **Open dialog both within TTF3 and towards outside …**
- **Solving problems like**
  - **Overlapping/collaboration with CEN (e.g.)**
    - TC 138 WG9
    - German national representatives
    - Gearing with ISO standards like ISO/IEC 17025
  - **Presence of large (non-nuclear) industry at the meetings**
- **Dissemination work:**
  leaflets, newsletters, mailshots, e-mailshots
- **Clustering**
  - ***Joint projects with TTF7 (hydrogen damage)***
  - ***Joint projects with TTF5 (remaining life)***
- **Next Workshops:**
  - **EPERC Workshop, October 2001, MPA Stuttgart**
  - **3rd European-American Workshop on NDE Reliability Berlin, Sept. 2001**

Workshop in Stuttgart, Oct. 5, 2001

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A workshop rganized in the framework of and
in conjunction with 27th MPA Seminar

Stuttgart, Germany, October 5, 2001

EPERC (European Pressure Equipment Research Council) Workshop on

In-Service Inspection and Life Management of Pressure Equipment

- Technical Task Forces 3, 5 and 7 -

2.2. A. Eriksson
Harmonization in the area of qualifications

- *Abstract*
- *Presentation*

PROGRESS OF HARMONIZATION IN THE AREA OF QUALIFICATIONS. EPERC-TASK FORCE ON INSPECTION HARMONISATION

A. Eriksson (Co-Chairman of TTF3)
European Commission – DG JRC – Institute for Energy

Abstract

Development of Inspection Qualification Methodologies has been significant over the last 10 years, mainly in the nuclear field, but lately also in the non-nuclear field. To a large extent actions were taken after the conclusions from international nuclear safety studies like PISC. This round robin study on nuclear components showed that NDT can, if properly applied, meet its ISI objectives, but the scatter in results where so wide that it was concluded the in order to get confidence in the reliability of an NDT system it was necessary to demonstrate its capabilities.

In Europe the Nuclear utilities formed ENIQ – European Network for Inspection Qualification, which developed their European Methodology for Qualification of NDT in 1995. In parallel, the European regulators wrote a document stating their common position on the matter in1996, which led to a revision of the ENIQ document, and a 2nd issue was published in 1997. The principles of ENIQ are implemented in national qualification schemes in most European countries. In the US, specific requirements for performance demonstration of ISI were introduced in the ASME code 1989. In 1998 IAEA published "Methodology for Qualification of ISI Systems for WWER Nuclear Power Plants", as part of their regional project in CEEC and NIS Improvement of Primary Circuit Components. General principles are in agreement with ENIQ.

In the non-nuclear field initiatives has been taken by EPERC TTF 3 and by CEN. CEN TC 138 WG 9 has written a report, which is due for CEN inquiry. Their methodology is intended for all kinds of NDT, where as TTF 3 is focused on pressure equipment only.

EPERC

European Pressure Equipment Research Council

Harmonization in the Area of Inspection Qualification

A. Eriksson
Institute for Energy
EC-JRC, Petten

EPERC

Outline

- ENIQ Nuclear application in Europe
- IAEA Nuclear Application VVER in CEEC
- PDI Nuclear US
- TTF3 Non-nuclear Pressure Equipment
- CEN Non-nuclear, all NDT

Definition

NDT Qualification:

ENIQ: The systematic assessment, by all those methods that are needed to provide reliable confirmation, of an NDT system to ensure it is capable of achieving the required performance under real inspection conditions.

CEN: Confirmation by examination and provision of objective evidence that the particular requirements for a specific use of NDT are fulfilled. NDT qualification is part of the qualification process.

ENIQ – Nuclear

European Methodology for Qualification of NDT

- Qualification of the NDT system components:
  - procedure
  - equipment
  - personnel
- Qualification based upon appropriate mixture of
  - practical test piece trials (open/blind)
  - technical justification

EPERC

Qualification approach: Test piece trials

- Blind/non-blind
  - procedure/equipment: non-blind
  - personnel: blind
- Test pieces:
  - replica of component
  - simple test pieces can be used
- Defects:
  - real defects
  - artificial simulations

October 5, 2001 TTF 3/5/7 Workshop 5

EPERC

Qualification approach: technical justification

- Complement/reduce test piece trials which can never provide sufficient statistical evidence
- Provide sound technical basis
- Take into account practical limitations if properly controlled (essential parameters)
- Evidence for technical justification:
  - modeling
  - experimental evidence: results from round robin trials, field experience, laboratory trials, etc.
  - parametric studies

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ENIQ - History

- 1995: First issue European Methodology for qualification of NDT
- 1996: Common position European Regulators on on qualification of NDT systems for PSI and ISI of LWR components (EUR 16802)
- 1997: Second issue European Methodology (EUR 17299)
- 1996-99: ENIQ pilot study
- 98-2001 Publication of ENIQ recommended practices
- 2000-02 2nd Pilot Study (to explore possibilities with TJ)
  European position on Risk-Informed ISI

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ENIQ – Document Hierarchy

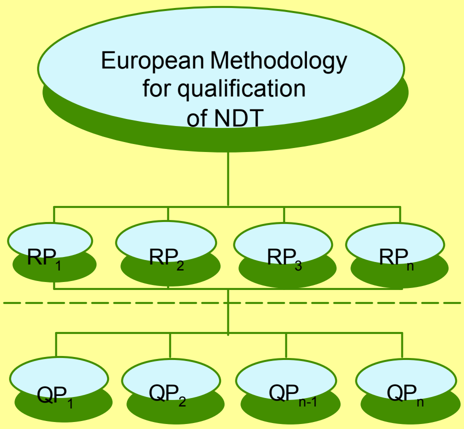
General philosophy

Recommended Practices

ENIQ contribution

Specific application at national level

Qualification Procedures



Applies to
All Countries
All Test Methods
All Components

Applies to
All Countries
All Test Methods
All Components

Specific Organisation
Specific Component
Specific Procedure

EPERC

ENIQ – Implementation

- Inspection Qualification principles of the European Methodology implemented in national qualification schemes in most European countries.
- Implementation shows a variety of national approaches.
- ENIQ is working towards a recognition of qualifications in different countries.
- As a part of the ENIQ methodology a particular qualification may be transferred via TJ.

EPERC

IAEA

- Regional Project in CEEC and NIS: Improvement of Primary Circuit Component Integrity
- IAEA has developed "Methodology for Qualification of ISI Systems for WWER Nuclear Power Plants", IAEA-EBP-WWER-11, 1998
- General principles in agreement with ENIQ
- Reflect special conditions in countries with WWERs
- Larger role is given to the NPP
- Feasibility study trough a Pilot study in Bulgaria

EPERC

PDI in USA

Performance Demonstration Initiative

- Formal requirement for performance demonstration of ISI for NPPs in USA with the 1989 version of ASME, Section XI, Appendix 8
- Response: Performance Demonstration Initiative by the industry (EPRI)
- More generic qualifications (as compared to ENIQ, which is specific)

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PDI in USA

Performance Demonstration Initiative

- Limited to ultrasonic inspection, but most inspections covered
- Personnel and procedure qualification
- Based on practical trials on a large number of test pieces

EPERC

TTF 3

- Initiated a development of an Inspection Qualification Methodology specifically for Pressure Equipment Industry
- Input from ENIQ, early CEN draft, experience from PISC, NORDTEST, PANI etc.
- DG ENTR support for pre-normative research in support of the PED
- Draft available
- Future: Awaiting the outcome of CEN TC 138 WG 9

EPERC

CEN TC 138 WG 9

Methodology for Qualification of Non-Destructive Tests

- Mandate: Prepare a technical report on the subject
- To much resistance in CEN TC 138 to make a European standard
- In support of the New Approach Directive “Pressure Equipment” Directive 97/23/EC
- Target dates:
  - June 1999, first meeting
  - June 2001, report ready for CEN inquiry

EPERC

CEN TC 138 WG 9

- Scope: "..document gives general guidelines to follow in carrying out qualification of non destructive testing, i.e. methods of assessing the capability of NDT to achieve the specified objectives for a defined application"
- applicable to all NDT methods
- considers qualification of equipment, procedure and personnel training
- decision to qualify is to be agreed between parties involved

EPERC

CEN TC 138 WG 9

Reference documents:

- European methodology developed by ENIQ
- UK BSI draft Standard
- German DIN document
- Above documents were combined to for basis of new Technical Report

EPERC

CEN TC 138 WG 9

Methodology for Qualification of Non-Destructive Tests

Phase 1: Prior to NDT qualification
Phase 2: Planning of NDT qualification
Phase 3: Conducting NDT qualification
Phase 4: Acceptance of NDT qualification

EPERC

CEN TC 138 WG 9

Membership

Convenor: Dr M. Bieth, EC – Joint Research Centre

Members are Representatives from:
- **Denmark**
- **Finland**
- **France**
- **Germany**
- **Italy**
- **Spain**
- **Sweden**
- **United Kingdom**
- **EC-JRC**

EPERC

Qualification Body

Requirements on an Inspection Qualification body

ENIQ: Independent, EN 45004, type A or B, ad hoc
EN 473 level II, III

Sweden: EN 45004, type A

Bulgaria: EN 45004 type B

IAEA: EN 45004, type A or B

But what about criteria for the assessment?

2.3. A. Jovanovic, L. Fabbri
EPERC Activities in the area of Risk-Based Inspection (RBI) and Risk-based Life Management (RBLM): RIMAP Network

- *Presentation*

EPERC Activities in the area of Risk-Based Inspection (RBI) and Risk-based Life Management (RBLM): RIMAP Network

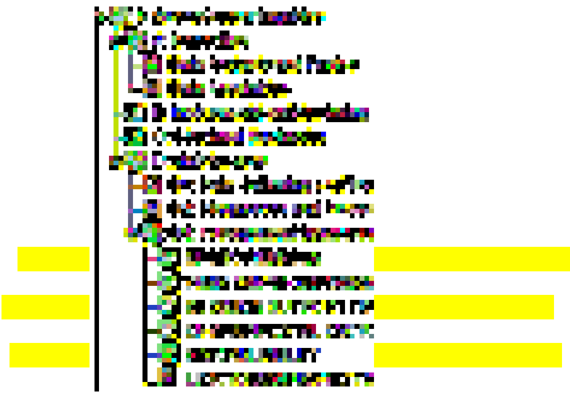
A. Jovanovic, L. Fabbri

EPERC Workshop, October 5, 2001

Stuttgart, Germany

EPERC inquiries in PAIS (PLAN Project)

- **Clusters**

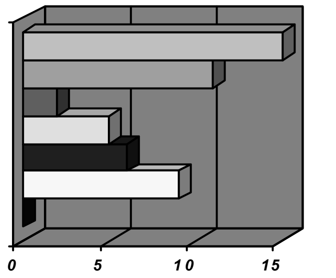


Results

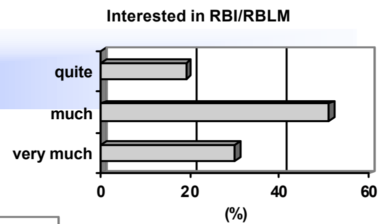
Results for question: Q1

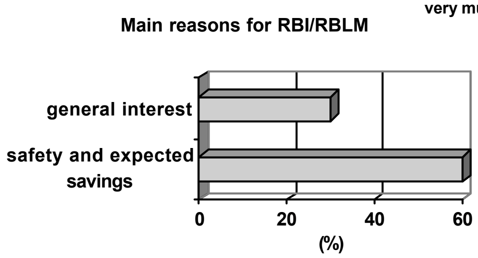
Which RBI approach(es) is/are used in your company?

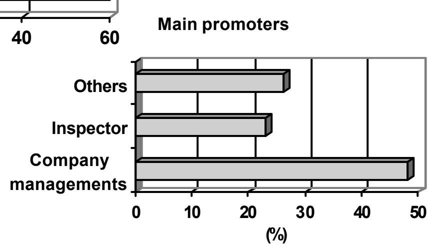
Total number of answers	**43**
ASME RBI Guidelines	15
API RBI Guidelines	11
KINT reports	2
DNV reports	5
Others, please specify!	6
None, but we would like to do something about it…	9
None, we do not care about any “risk-based" stuff	0



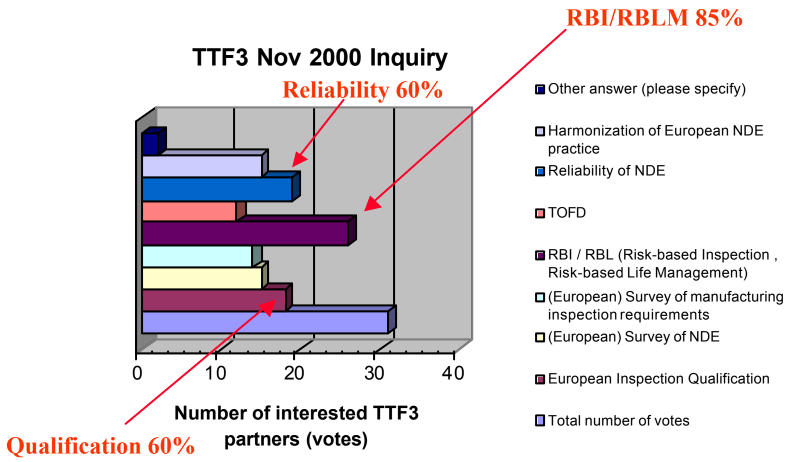
Results - interests







Future needs:
Results of the TTF3 inquiry November 2000



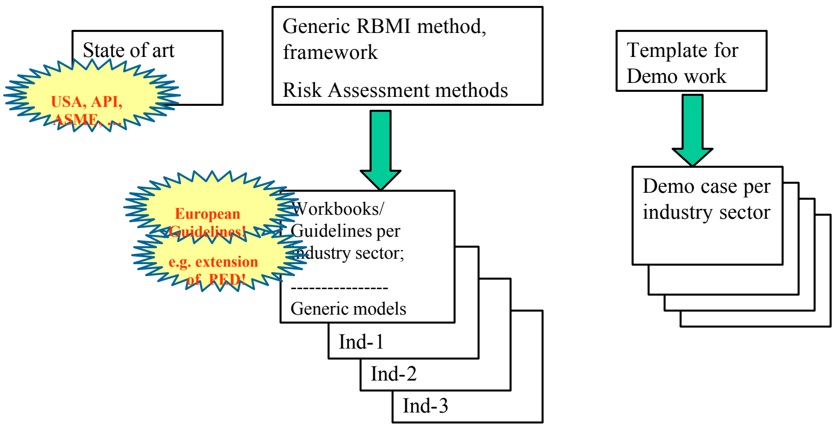
Results/reports in PAIS

RIMAP

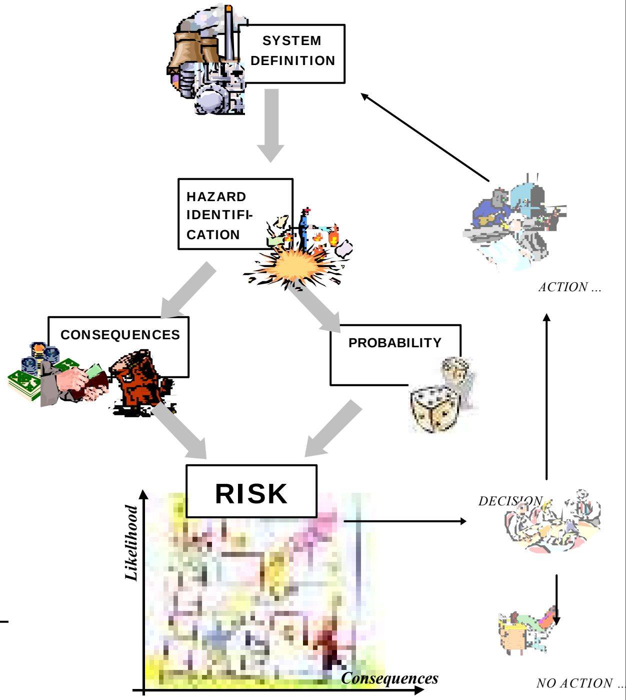
Risk **B**ased **I**nspection and **Ma**intenance **P**rocedures

- **Goal:**
  Development of a European Guideline for Risk/Based Inspection and Risk-Based Life Management (RBLM)
  - Research and Demonstration Part of the Project (RIMAP RTD)
  - RIMAP Network
- **Solution**
  - 17 EU-Partners in RTD part
  - a Network with 34 EU and other Partners + ca. 20+ Observers
- **Deliverables**
  - European guideline, CEN Docs (future standards, link to PED), software...

RIMAP Deliverables



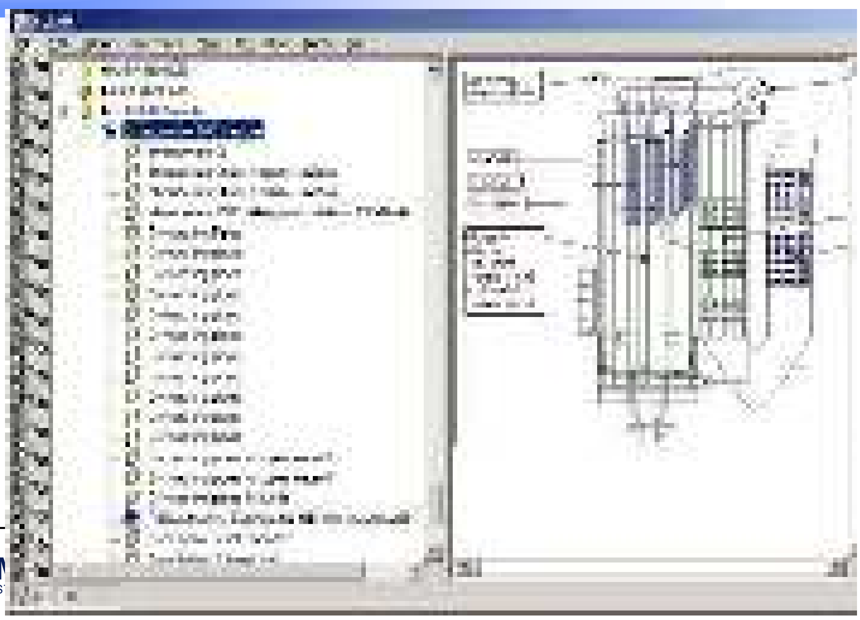
RISK =
probability
×
consequences

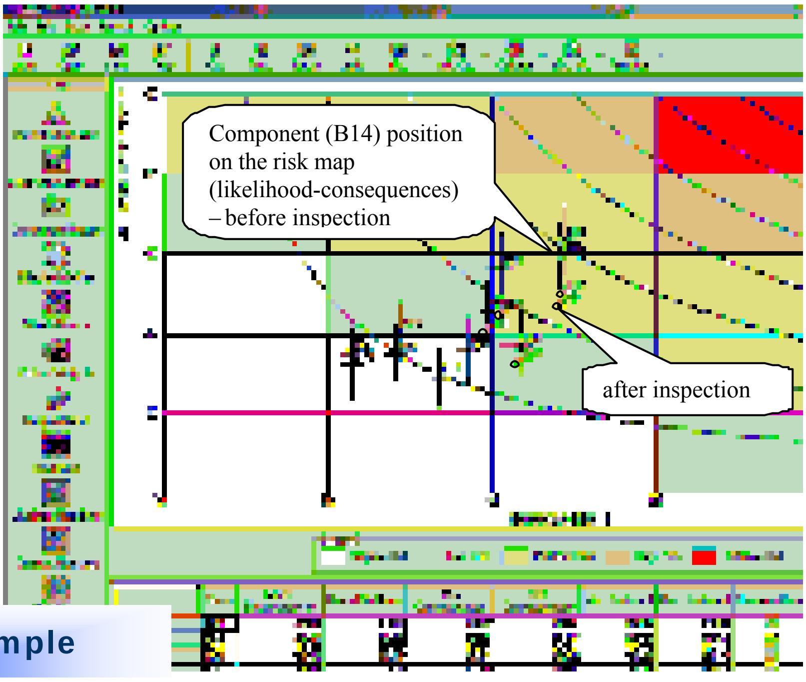


MPA STUTTGART

1st – 2nd October 2001
Santander, Spain

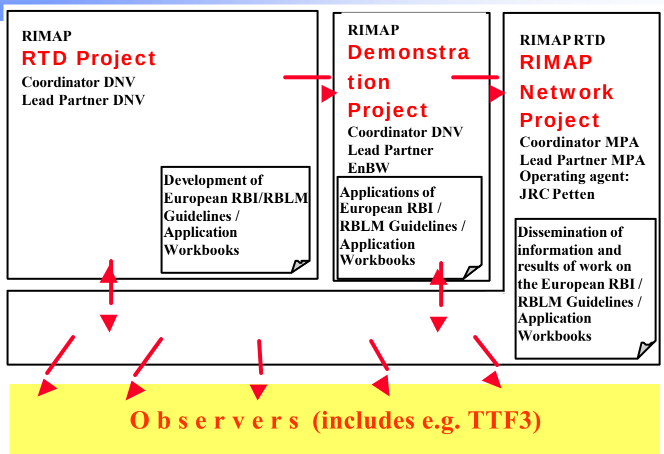
Examples





Example

RIMAP Project(s)

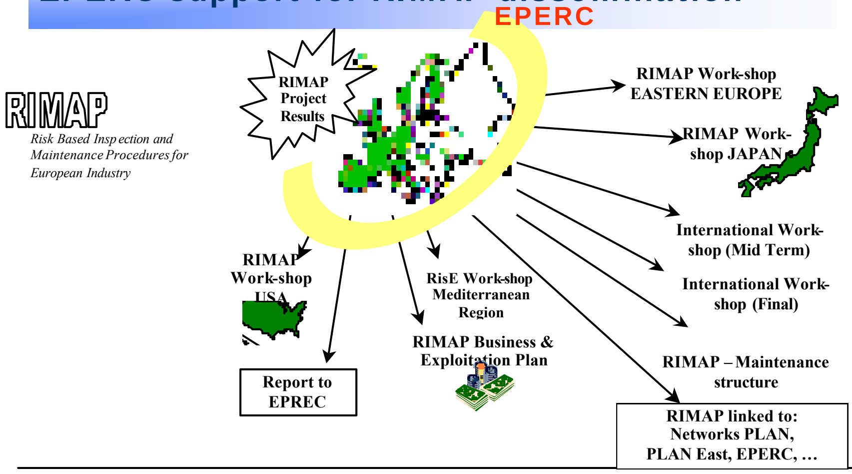


RIMAP Partners

Nr	Partner	Country
1	MPA	Germany
2	JRC Petten	The Netherlands
3	DNV	Norway
4	VTT	Finland
5	TÜV	Germany
6	TNO	The Netherlands
7	HAS	The Netherlands
8	EnBW	Germany
9	Siemens	Germany
10	ESB	Ireland
11	EdF	France
12	Corus	UK
13	Electrabel, Laborel.	Belgium
14	IEC	Israel
15	Bureau Veritas	France
16	Monition	UK
17	Metalogic	Belgium

Nr	Partner	Country
18	AiB Vincotte	Belgium
19	CorrOcean	Norway
20	TWI	UK
21	UWS	UK
22	BZF	Hungary
23	ISQ	Portugal
24	Technologica	Belgium
25	MIT	Germany
26	Force Inst.	Denmark
27	HSE-HID	UK
28	Allianz	Germany
29	Totalfina Elf	France
30	Geodeco	Italy
31	Marintek	Norway
32	ERA	Great Britain
33	Exxon	UK
34	Petrobras	Brazil

EPERC support for RIMAP dissemination



Conclusions

… we have been on the right track!

MPA STUTTGART

1st – 2nd October 2001
Santander, Spain

POWER STATION ACCIDENT

High Cost Reduction pressure

After the explosion in the coal power station Weisweiler near Aachen, when **six workers were seriously hurt**, the authorities are checking whether **the accident has been caused by the drastic saving measures leading finally to safety problems**. After liberalisation of the electricity market in Germany three years ago, the five power stations of RWE / Rheinbraun have been under enormous pressure to reduce costs. In Weisweiler, **the staff of 1030 at the end of 1999 has been reduced to present 708**. The national office for industrial safety in Aachen investigates the indications, saying that **due to cost saving the systems were no longer so often cleaned and controlled**. Coal dust at the conveyors could have led to the jamming and the following fire two weeks ago. "We check the rosters before and after the dismissal wave", said the deputy director of the authority Mr. Reinhard Hahn, who also asked for a "detailed examination of possible weak points" of the entire system. Pressure to reduce costs is present everywhere, admits Johannes Lambertz, the power station manager in Rheinbraun, but with the protection of persons however "there were no risks allowed". **The damage in Weisweiler in is estimated to be over 20 million Marks**.

Der Spiegel 34/2001

2.4. G. Våge, S. Angelsen, A. Jovanovic RIMAP RTD Project: Developing of the European Guideline for Risk-based inspection and maintenance

- *Paper*
- *Presentation*

Risk Based Inspection and Maintenance Procedures for European Industry[*]

RIMAP project

Risk Based Inspection and Maintenance Procedures for European Industry (RIMAP) is a European project that aims at developing a unified approach to making risk based decisions within inspection and maintenance. The project started on March 1, 2001 and will run for three year. The project has a large industry participation:

Det Norske Veritas (Project co-ordinator)	(NO)	ExxonMobil Chemical Ltd	(UK)
Bureau Veritas	(F)	Energie Baden-Württemberg Ingenieure GmbH	(D)
Statliche Materialprüfungsanstalt (MPA Stuttgart)	(D)	Siemens Aktiengesellschaft	(D)
Technical Research Centre of Finland (VTT)	(Fin)	European Commission, Directorate General Joint Research Centre, Petten	(NL)
TÜV Süddeutschland Bau und Betrieb GmbH	(D)	Electricity Supply Board	(IRL)
Netherlands Organization for Applied Scientific Research (TNO)	(NL)	Corus UK Ltd.	(UK)
Hydro Agri Sluiskil B.V.	(NL)	DOW Benelux N.V.	(NL)
Mitsui-Babcock Technology Centre	(UK)	Solvay S.A.	(B)

* Risk Based Inspection and Maintenance Procedures for European Industry (RIMAP) is a project partly financed by the European Commission for the "Growth Programme, Research Project RIMAP Risk Based Inspection and Maintenance Procedures for European Industry"; Contract Number G1RD-CT-2001-03008.

RIMAP overview

Background: Current practice to inspection and maintenance planning is for most industries based on tradition and prescriptive rules, rather than being an optimised process where risk measures for safety and economy are integrated. New technology for taking risk based decisions is emerging within a broad range of sectors, and has proven to be a very efficient tool (Fig. 1). However, there is a great need to define the technical content, links to local legislation and to integrate this approach with the day-to-day operation.

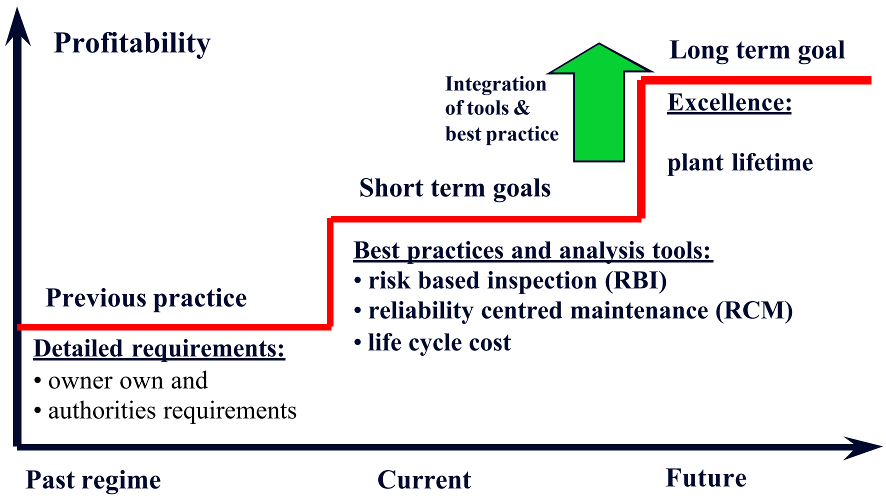


Figure 1 The evolution of decision making in inspection and maintenance.

This is the main background for the RIMAP project, where a consortium of 16 European companies representing a broad industry base have joined forces to develop a European best practice and to demonstrate its applicability in several case studies. The project addresses the petrochemical, chemical, steel works and the power industry in particular, but the techniques can easily be extended and be used in other industry sectors as well.

Objective: The objective of the project is to define a unified approach to making risk based decisions, within the field of inspection and maintenance (Fig.2). Risk is here understood as the combined effect of probability of failure and the consequence of a failure (personnel safety, quality of product, environmental damage, and economic loss).

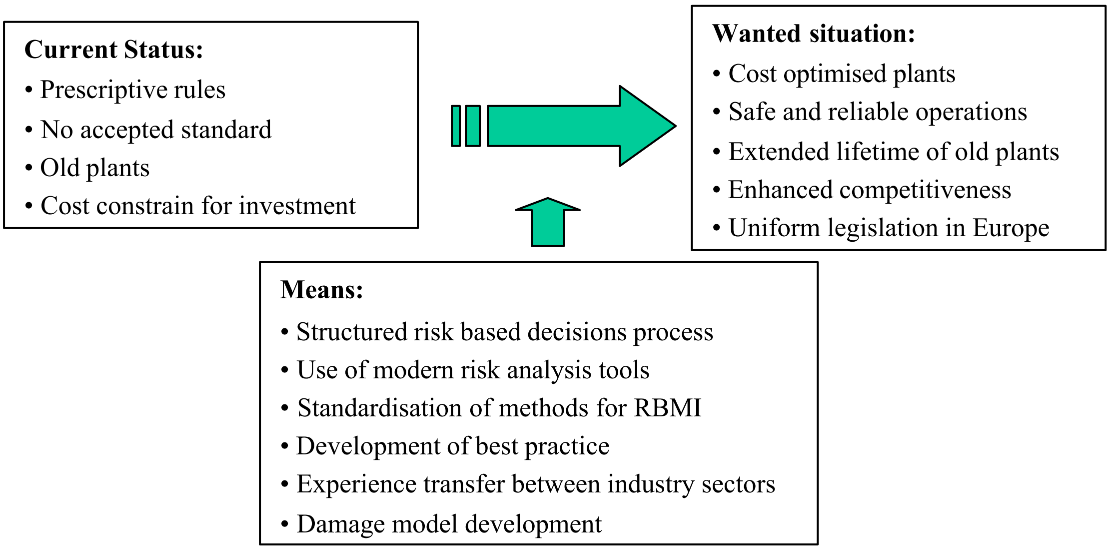


Figure 2 RIMAP objective: to develop unified approach for risk based decisions within inspection and maintenance.

The main benefits of the work will be:

- cost-optimised inspection/maintenance plans that will save operational and risk costs in the order of 10 to 40% for the involved industries
- improved safety for plant personnel and the society en-large
- a technical framework for a European standard

European technology progress and social benefits: There is a great need for standardisation within the area of inspection and maintenance in Europe (ref. EPERC - European Pressure Equipment Research Council). Several initiatives in the US (API, ASME & EPRI) have proven to be successful, but these may not be in line with European legislation and design practice within safety and environment.

The RIMAP project aims at:

- Developing a unified approach to risk based maintenance and inspection planning
- Setting requirements to the contents of an analysis, personnel qualifications, and tools
- Forming the basis for future standardisation in this area.

Scope of Work: The project is organised in one RTD phase (RIMAP RTD) and one demonstration phase (RIMAP DEMO).

The RIMAP RTD project is divided in 5 main technical work packages (Figure 4, page 10), in addition to administration. 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: guidelines for development of Risk Based Inspection and Maintenance plans.
- WP5: Validation of the RIMAP methodology.
- WP6: Project management

The RIMAP DEMO is organised in 5 work packages:

- RIMAP DEMO 1: Industry group: Petrochemical.
- RIMAP DEMO 2: Industry group: Power Industry.
- RIMAP DEMO 3: Industry group: Steel works.
- RIMAP DEMO 4: Industry group: Chemical
- RIMAP DEMO 5: DEMO Support

Deliverables: The main deliverables from the RIMAP RTD project will be:

- A method describing a unified approach to maintenance and inspection planning based on risk decision criteria and cost optimisation.
- Documented validation and testing of the method within several major industry sectors.
- 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 standardisation.

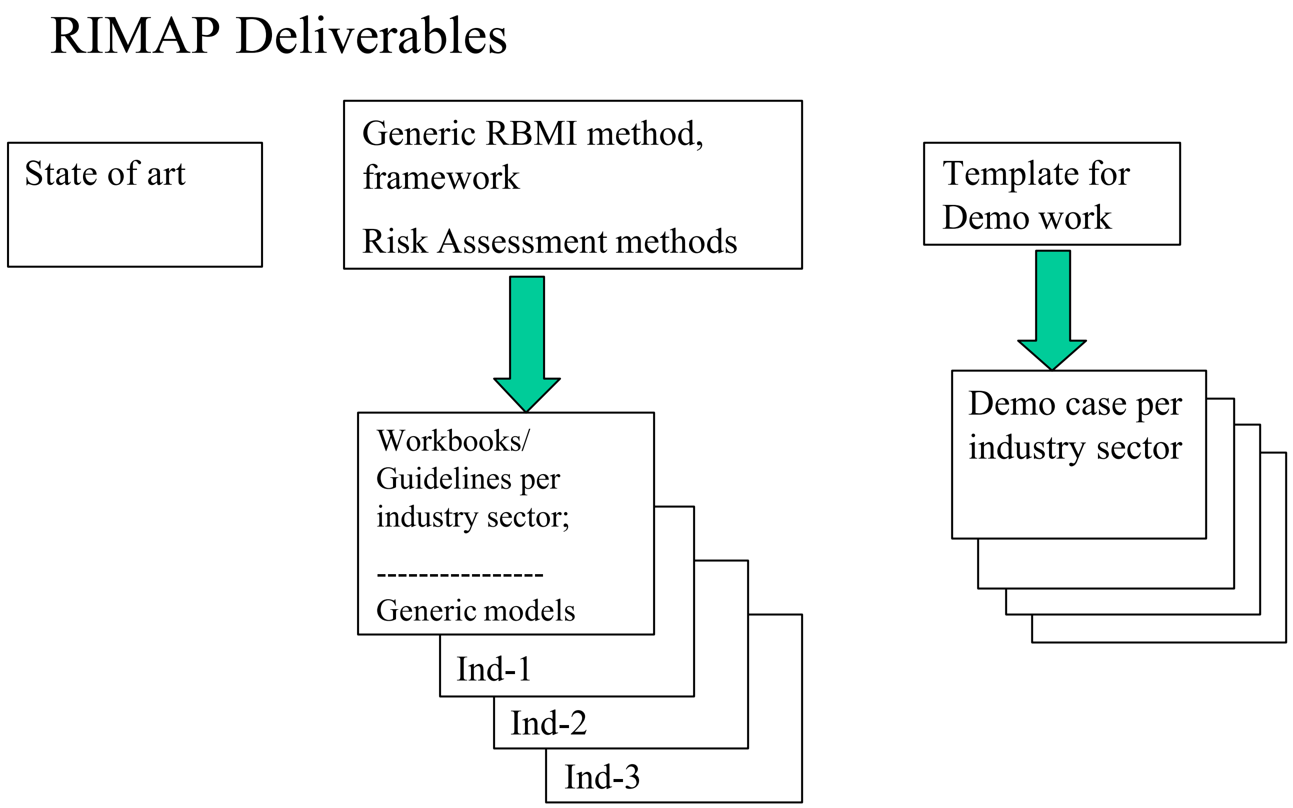


Figure 3 Overview of RIMAP deliverables

Networking:

The RIMAP project will co-operate with the RIMAP Thematic Network (see http://www.mpa-lifetech.de/rimap) to establish the state-of-the art, and use this as a basis for further development of the technical framework for a European Standard. The generic RBMI method will be supplemented by RIMAP workbooks, that is industry sector specific guidelines. The workbooks will contain instructions on how to use the RIMAP methodology in the industry. As there are a number of competing software packages supplied by RIMAP partners available at the market, the RIMAP project will not favour any of those directly, but rather recommend when it can be effective to apply a software package. The software packages are usually flexible enough to be linked to the clients systems. It will also be developed a general workbook aimed at industries that are not directly taking part in the RIMAP project, in order to enable wider application of the project results. The templates for the RIMAP Demo work will contain a detailed description on how the Demo sites are expected to carry out the demonstration in order to demonstrate the usefulness of the RIMAP methodology in a uniform way to enable learning across industries.

The work will be disseminated via the RIMAP Thematic network and several existing networks like EPERC, workshops, seminars, and papers in order to achieve acceptance and feedback for the methods. Public project results will be disseminated through the RIMAP web site (http://research.dnv.com/rimap), and e-mail notifications will be sent to main stakeholders and interested parties whenever major updates of the web site are made.

Innovation: The main innovation aspects of the RIMAP project are:

- The integration of maintenance (RCM) and inspection (RBI) into a uniform decision process with balanced effort between the expenditures.
- The use of probabilistic decision analysis for process systems is in its infancy, in particular when it comes to use of inspection and monitoring data. This will be explored and tested in the case studies.
- Combining the theoretical modelling of plant failure ("hard" knowledge) with plant experience ("soft" knowledge) will be developed into a rational method.
- Technology transfer between industry sectors, i.e. some sectors have used risk based decision for many years, whereas other have not. The project will facilitate such transfer.

Goals and Benefits: The expected benefits of the RIMAP project are;

- For the plants/end-users: Savings in operational expenditures and failure costs. A clearly defined philosophy for how the planning can be done.
- For the inspection companies: Tailoring of tools and methods to satisfy the industry needs and give awareness of their limitations.
- Regulators: Knowledge and ability to set proper requirements to the Risk based decision analysis work performed at the plants. Derive a technical basis for a new standard in the field.
- Consultants: A framework for providing enhanced services for the industry in particular during plant-networking and outsourcing.

Contacts: For further information see

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

or contact

Sture Angelsen
Mail: Det Norske Veritas, N-1322 Høvik, Norway.
E-mail:rimap@dnv.com
Phone: (+47) 67 57 91 77
Fax: (+47) 67 57 99 11
Url: http://www.dnv.com

Appendix

The work in the RTD part of the RIMAP project is organised in five technical workpackages (WP1 to WP5).

WP 1 is a description of the State-of-practice within the industry sectors involved in the project, hereunder the different available methods used in inspection and maintenance planning. The aim is to describe the present practice, experience with the different techniques used for planning, inspection and testing. This WP will act as a general knowledge platform for the companies involved as well as give guidance and directions for the further development work in RIMAP. This task will receive information from the RIMAP thematic network and from the existing EPERC organisation.

WP 2 aims at developing and defining a common framework for decisions related to maintenance and inspection. The RCM methodology will be applied, but expanded to include *predictive* probability of failure assessment as used in RBI and RBLM (Risk-based Life Management). Multi-criteria decision logic will be developed including acceptance criteria, risk matrixes for safety, environment and financial costs. The European standards within design and maintenance will be adhered to as far as possible. The generic framework developed in WP 2 will be the platform for the further work in the other work packages.

WP 3 concerns risk assessment methods and will develop, test and document the calculation process used to assess the high-risk components. Methods for estimating the Consequence of Failure (CoF) and Probability of Failure (PoF) (or lifetime if relevant) will be described and in particular the effect of inspection data and monitoring results included (updated PoF). This task will also address the inspection/testing effectiveness in relation to the damage mechanisms in question, i.e. to consider the Probability of Detecting (POD) degradation of a component at an inspection. Both qualitative and quantitative techniques will be explored – the most important innovative feature in this WP will be the development of a new approach for determining and optimisation of the overall risk level for the whole plant. The approach will be generic, and intend to meet the need for an approach that is more flexible than existing approaches by being flexible enough to take advantage of both “hard” and “soft” data in one decision process. This will be a major improvement of the current state-of-the-art approaches (e.g. API). Software development will be done as part of this task, see below. Further, the issue of human factors will be addressed.

WP 4 will be devoted to the development of practical inspection/maintenance plans based on risk results decisions. This will be used to set-up risk reduction measures like inspection, testing, monitoring, replacement or any maintenance actions and address the practical aspects of this process (working process) and its implementation. A new (“mixed” qualitative/quantitative) approach for determination and optimisation of overall risk level for the whole plant will be developed – i.e. to determine where the risk-optimisation level will be the most beneficial. This WP will develop the RIMAP “Application Workbooks”, which will be validated in WP 5 and applied in the RIMAP Demonstrator project.

WP 5 is dedicated to verification and validation of the developed RBMI methodology and the RIMAP Application workbooks. The validation will be carried out through testing at some of the industrial sites that participates in RIMAP. Minor recommended improvements will be implemented, but recommendations that require extensive research or development will be used to propose further extensions of the methodology and the workbooks. Templates will be developed to guide end users on how to carry out the RIMAP demonstration.

The work in the **demonstration part of the RIMAP project** is organised in four technical work, one for each of the four industry sectors, and one support work package packages (WP DEMO 1 to WP DEMO 5). The RIMAP Demonstration project will demonstrate the applicability and value of the RIMAP methodology, including the Generic Method and the RIMAP Application Workbooks. The demonstration consists of testing and demonstration of RIMAP models and methods, use of the models and methods in practical application, documentation of results from each test case, and finally an overall comparison across industries and recommendations for further improvement and standardisation work. The templates developed in WP 5 will be used as guidelines.

The four industries covered by the RIMAP Demonstration project are:

WP DEMO 1: Petrochemical industry
WP DEMO 2: Power industry
WP DEMO 3: Steel Works
WP DEMO 4: Chemical industry

In addition there will be a Demo support and management workpackage (WP5).

The RIMAP combined project will work closely with the RIMAP Thematic Network (RIMAP TN). RIMAP TN will be used actively as a source of information, and as an instrument disseminate and discuss the preliminary results from RIMAP, and to ensure co-ordination and harmonisation with other ongoing related standardisation work. Interested parties can join the RIMAP Thematic Network as an observer.

Table 1 Project work packages

No	WP	Budget (PersonMonths)	WP-leader
WP 1	Current Practice	11	**DNV**
WP 2	Generic RBMI-method	30.5	**DNV**
WP 3	Risk assessment methods	66.7	**DNV**
WP 3.1	Probability of failure		**MPA**
WP 3.2	Consequence of failure		**TNO**
WP 3.3	Inspection efficiency (POD)		**MBEL**
WP 3.4	Human aspects and risk calculation		**DNV**
WP 4	RIMAP Application Workbooks	59.1	**MPA**
WP 5	Validation of the RIMAP methodology	29.5	**DOW**
WP6	Project Management	15	**DNV**
WP RIMAP DEMO	RIMAP Demonstration		
WP DEMO 1	Petrochemical	8	**ExxonMobil**
WP DEMO 2	Power Industry	22	**EnBW**
WP DEMO 3	Steel Works	4	**CORUS**
WP DEMO 4	Chemical	22	**DOW**
WP DEMO 5	Support	9	**DNV**
	Sum	**276.8**	

Relationship: Figure 4 illustrates the relationship between the RIMAP RTD work packages, the

interaction with the RIMAP Thematic Network. The RIMAP Thematic Network will function as an arena for gathering information on state-of-art in practise and academia, and a forum for dissemination of RIMAP results and discussion of the standardisation aspects of RIMAP.

RIMAP WP-relations

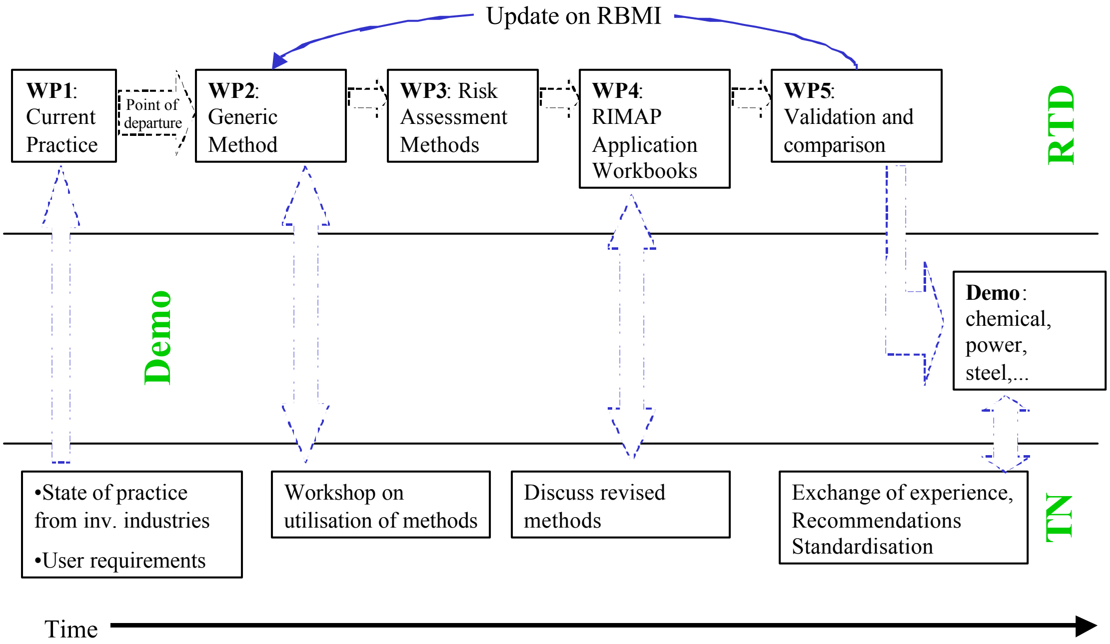


Figure 4 Relationship between the RIMAP RTD workpackages, the RIMAP Demo and the interaction with the RIMAP Thematic Network.

- o0o -

RIMAP

Risk Based Inspection and Maintenance Procedures for European Industry

EU-Funded Programme:

COMPETITIVE AND SUSTAINABLE GROWTH

4-04

MANAGING RISK

RIMAP

- EU-funded project (GROWTH Programme)
- Budget: 3.6 mill € (EU: 1.7 mill €)
  - RTD: 2.8
  - Demo: 0.9
  - Network: 0.9
- Duration: March 2001 to March 2004
- Number of participants;
  - RTD and Demo: 16
  - Network: 30++

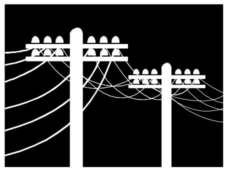
Partisipant

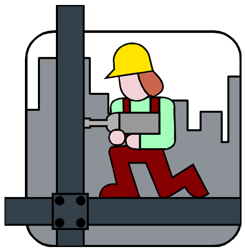
Det Norske Veritas (DNV)	Norway
Bureau Veritas (BV)	France
Staatliche Materialprüfungsanstalt (MPA)	Germany
VTT Manufacturing Technology	Finland
TÜV Engineering Service (TÜV)	Germany
TNO – INSTITUTE OF INDUSTRIAL TECHNOLOGY	Netherlands
Norsk Hydro (NH)	Netherlands
MITSUI BABCOCK ENERGY LIMITED (MBEL)	UK
ExxonMobil Chemical (Exxon)	UK
Energie Baden-Württemberg AG (EnBW)	Germany
Siemens AG (Siemens)	Germany
Electricity Supply Board (ESB)	Ireland
Corus	UK
The Dow Chemical Company (DOW)	Netherlands
Solvay	Belgium
Joint Research Centre of the European Communities (JRC)	Netherlands

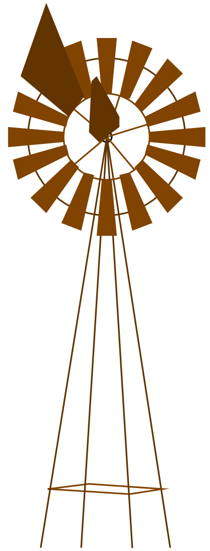
Type of industries

- petrochemical,
- chemical,
- (pulp & paper),
- steel works,
- power industry.

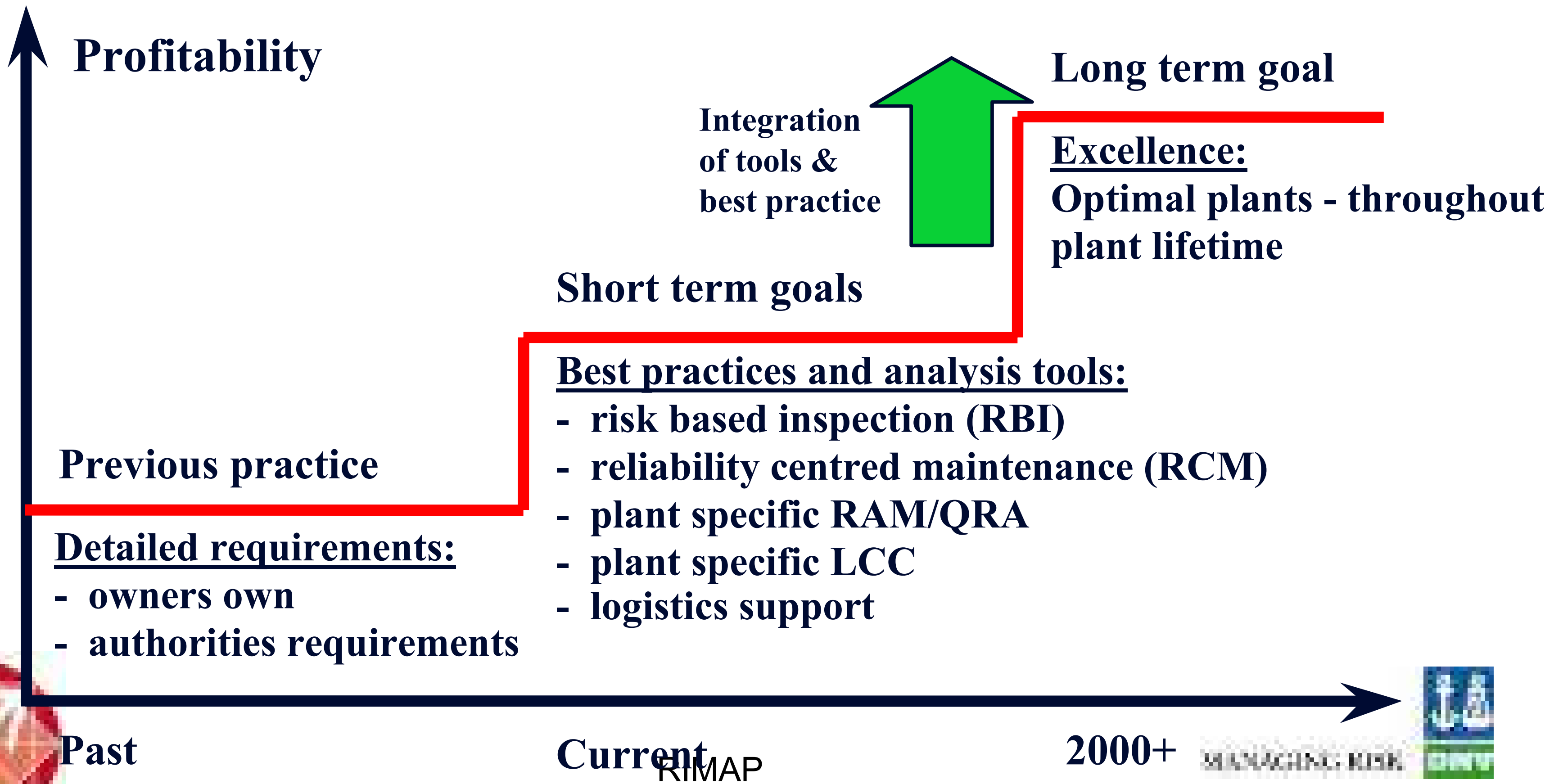
- the techniques can be extended and used in other industry sectors



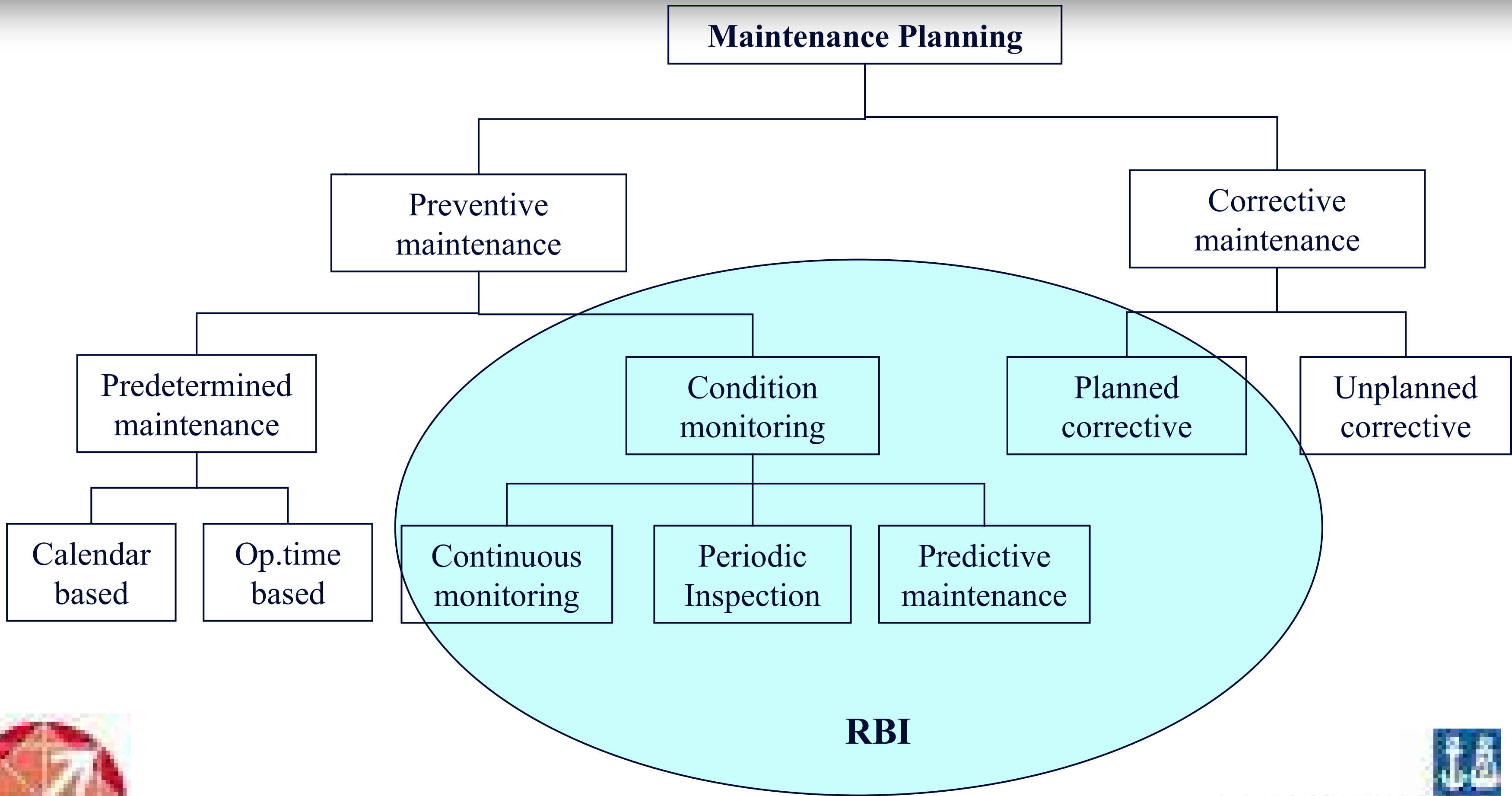




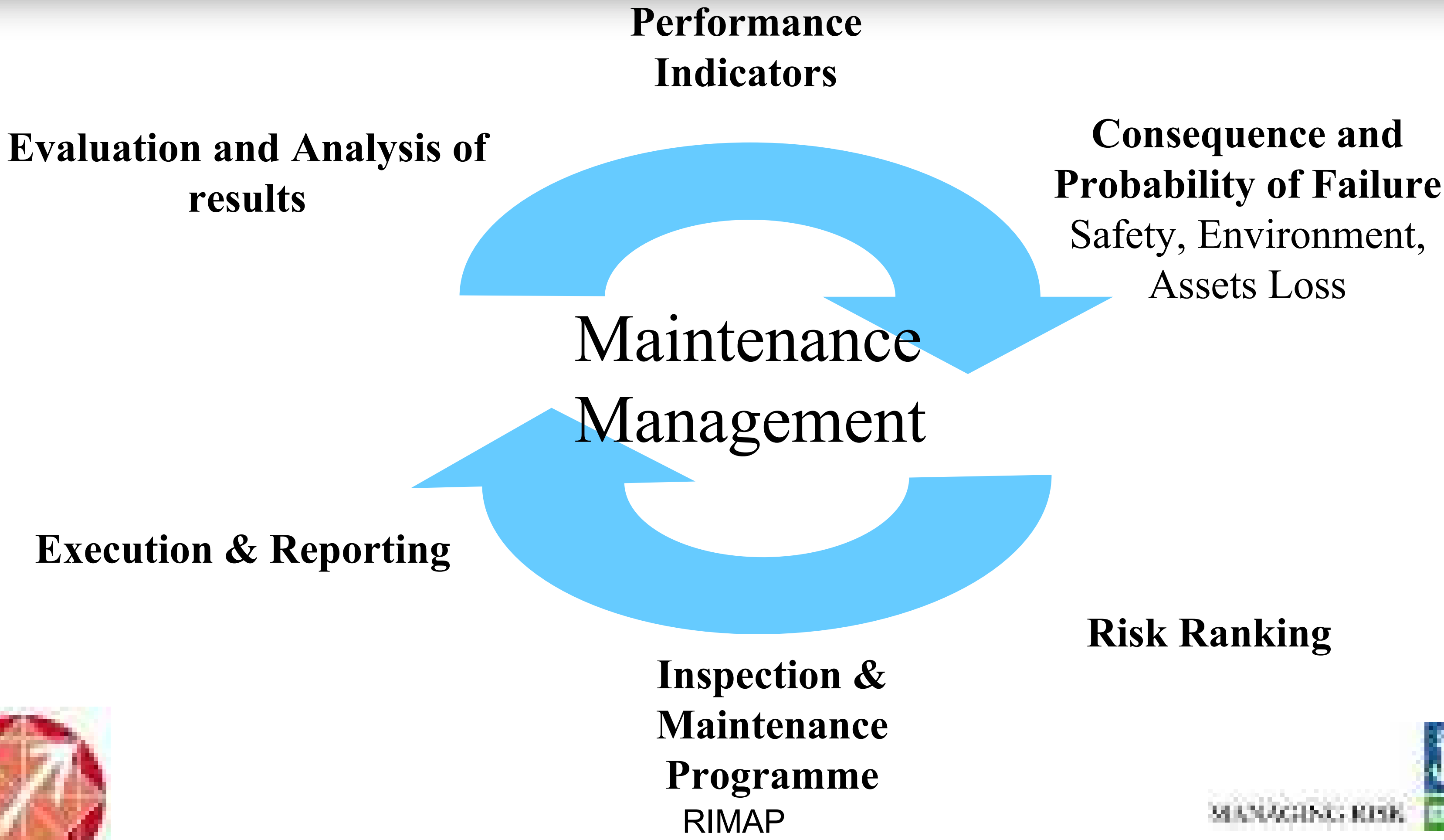
RBMI towards Excellence



Maintenance Planning



RBMI Philosophy



MANAGING RISK DNV

Background

Prescriptive legislation → **Goal setting standards**

- *But the industry don't know how to do this?!*
- *Large variety in quality of assessments*
- *No basis for audits by legislative bodies*

Objective (1)

- to define a unified approach to making risk based decisions within the field of inspection and maintenance
- safety/environment constraints
- cost-optimised

a technical framework for a European standard

Risk = Probability * consequence

Consequence :

- personnel safety,
- quality of product,
- environmental damage,
- economic loss

Objectives (2)

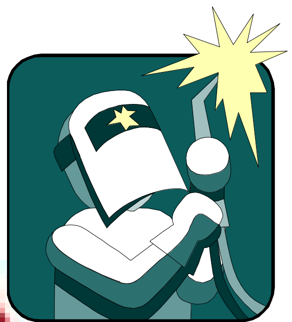
- Developing a unified approach to risk based maintenance and inspection planning
- Setting requirements to the contents of an analysis, personnel qualifications and tools
- Forming the basis for a future standardisation in this area.

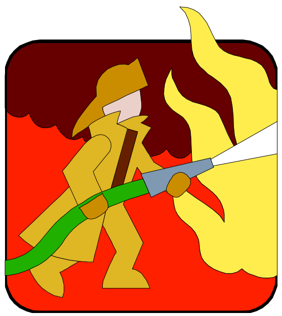
Risk

=Consequence of failure X **Probability for failure**

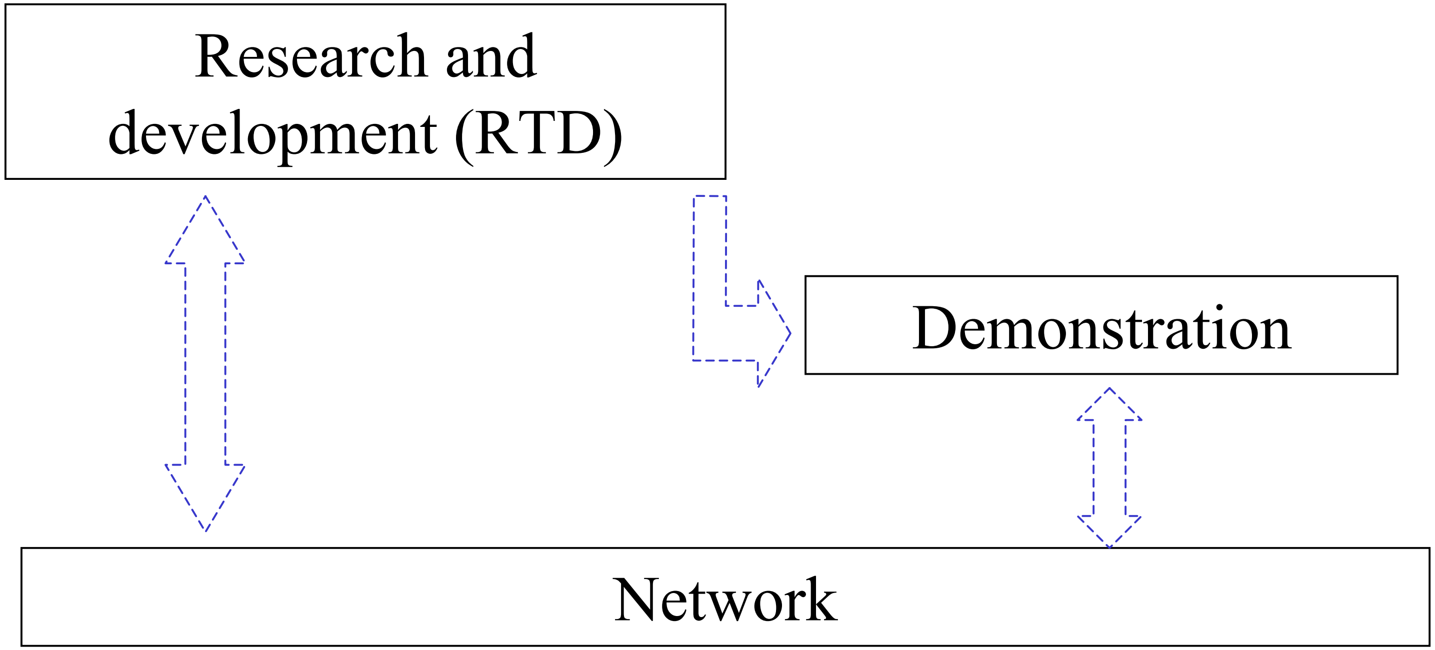
- Personnel
- Environment
- Economic
- Quality

- Failure mode,
- Material/Environment; degradation;type & rate,....
- Damage tolerance

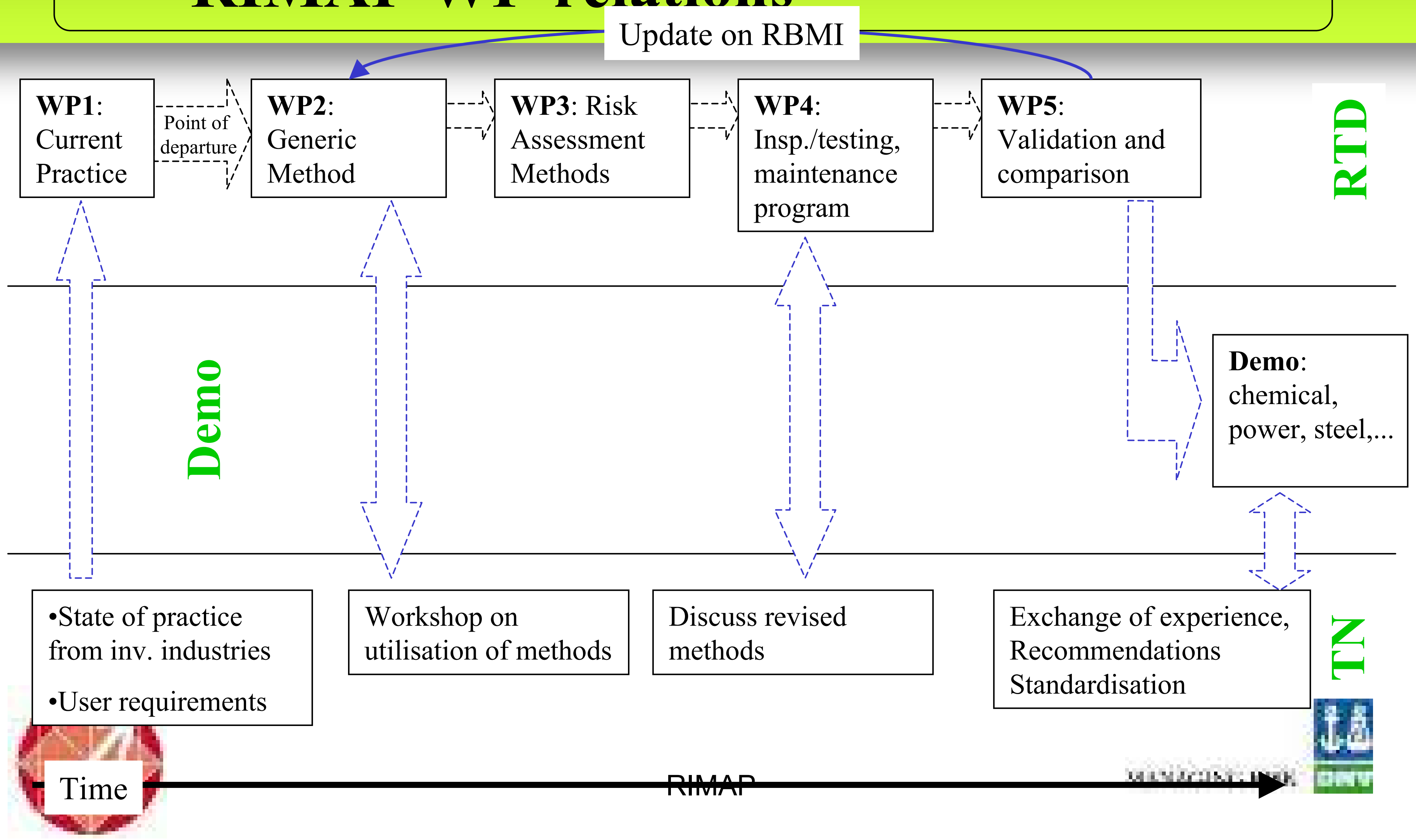




RIMAP Work packages



RIMAP WP-relations



WP1: State of art

- Define terminology
- Document state of art/practice in different industry sectors
  - –inspection planning
  - –maintenance planning
  - –evaluate pro/con
- Establish user requirements
- Identify available SW & tools
- Local and EU legislation limitations

WP2: RBMI Framework

Generic framework for RBMI decision

- risk based
- linked to overall safety/ environmental criteria
- combine qualitative & quantitative assessment
- data requirements
- regulatory aspects

Applied to:

- Pressure containing equipment
- facilities; electrical, rotating, instrument
- Safeguarding (protective) devices

WP3: Risk Assessment methods

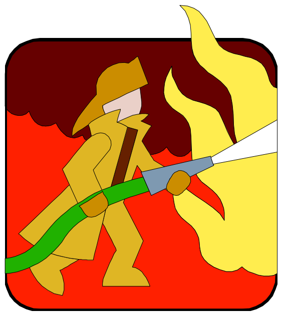
1: Probability of failure assessment
- damage mechanisms
- lifetime estimation

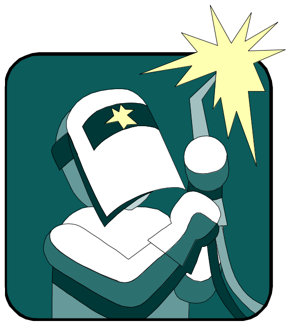
2: Consequence of failure assessment

3: Inspection/monitoring efficiency

4: Human aspects

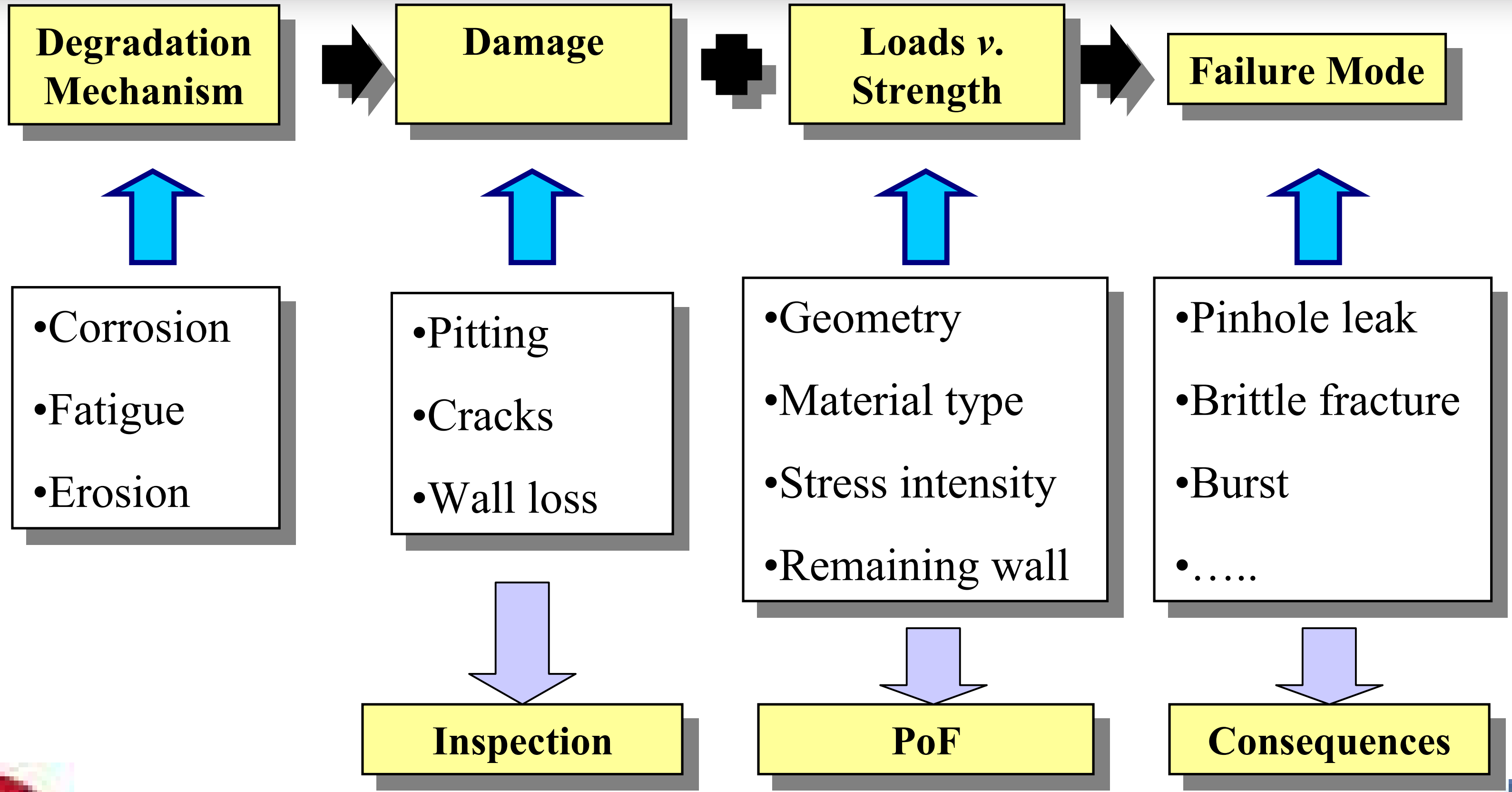
5: Risk aggregation





MANAGING RISK DNV

Calculation of PoF



Knowledge of Materials Tells Us What Failure Mode to Expect

WP4: RIMAP Applicaiton workbooks

1: Working process for the development of inspection/maintenance programme

–How, when, why

2: Risk reduction

3: Optimisation methods

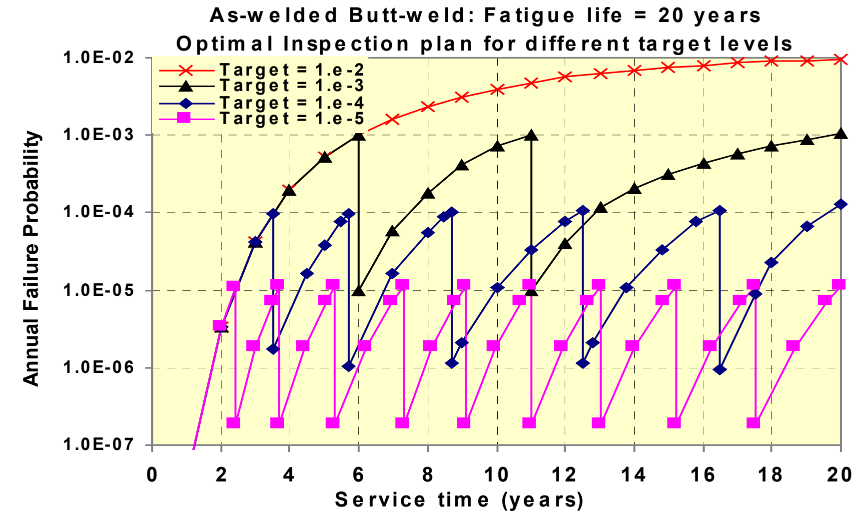
- safety/environment

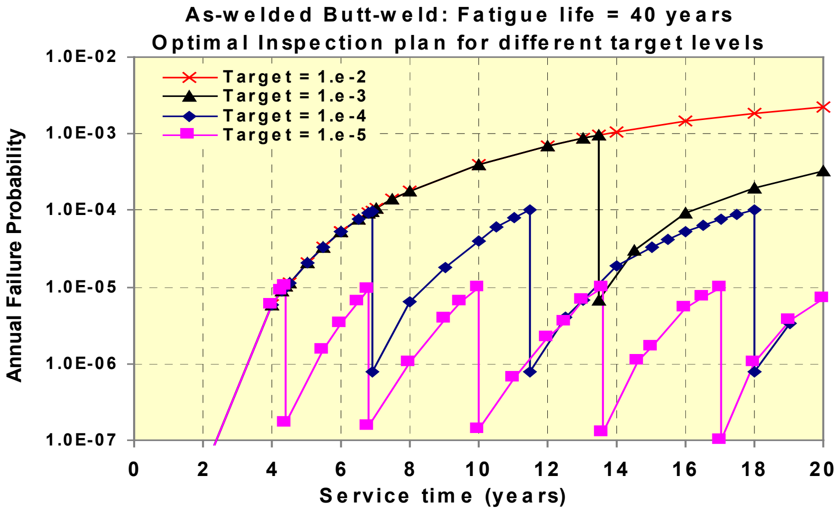
- cost-benefit

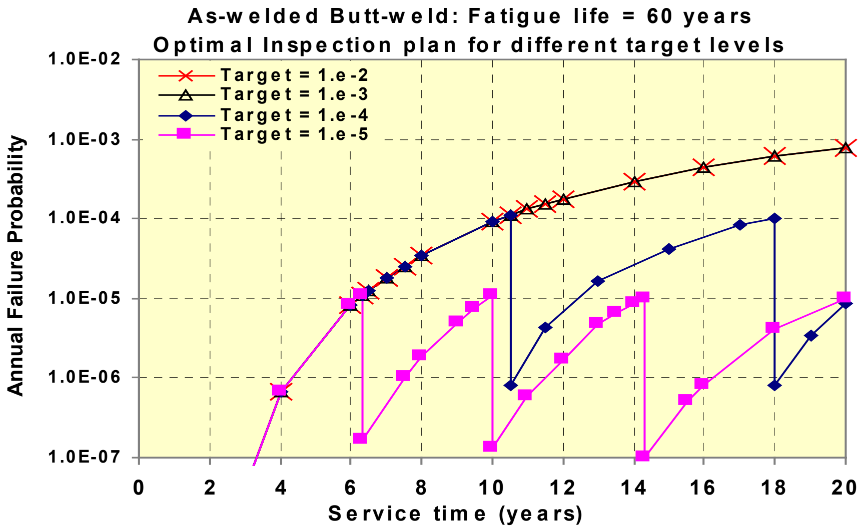
Deliverables:

- General workbook
- Workbooks per industry sector

Selection of inspection scheduling programme - Example





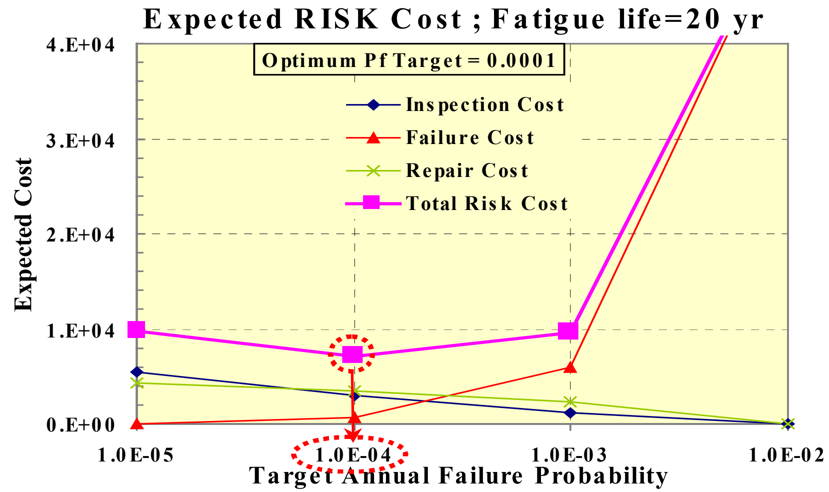


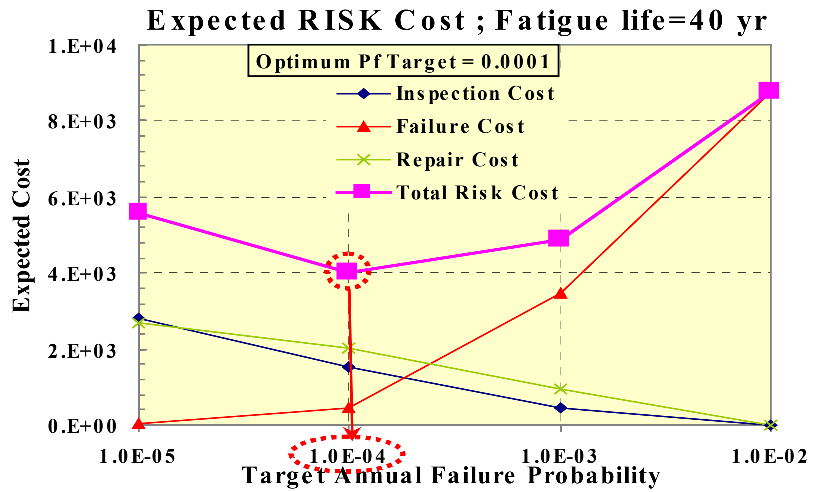
Cost terms:

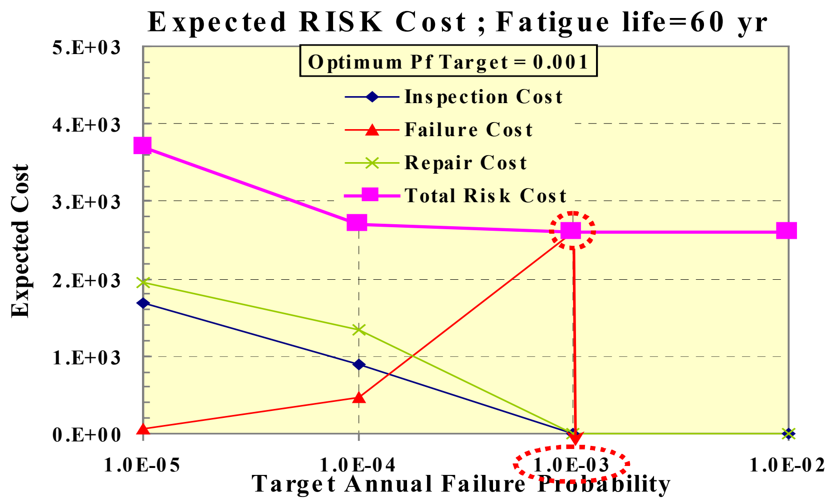
- **Expected Failure cost** $1.44 \cdot 10^6$ NOK
- **Expected Inspection cost** 1000 NOK
- **Expected Repair Cost** 10000 NOK
- **Discount rate:** 6%

MANAGING RISK DNV

Selection of inspection scheduling programme - Example







Number of inspection as function of target failure probability and fatigue life

Target Pf	Fatigue life (years)		
	20	40	60
1.0E-05	9	5	3
1.0E-04	5	3	2
1.0E-03	2	1	0
1.0E-02	0	0	0

Optimal Target = 10^{-4}

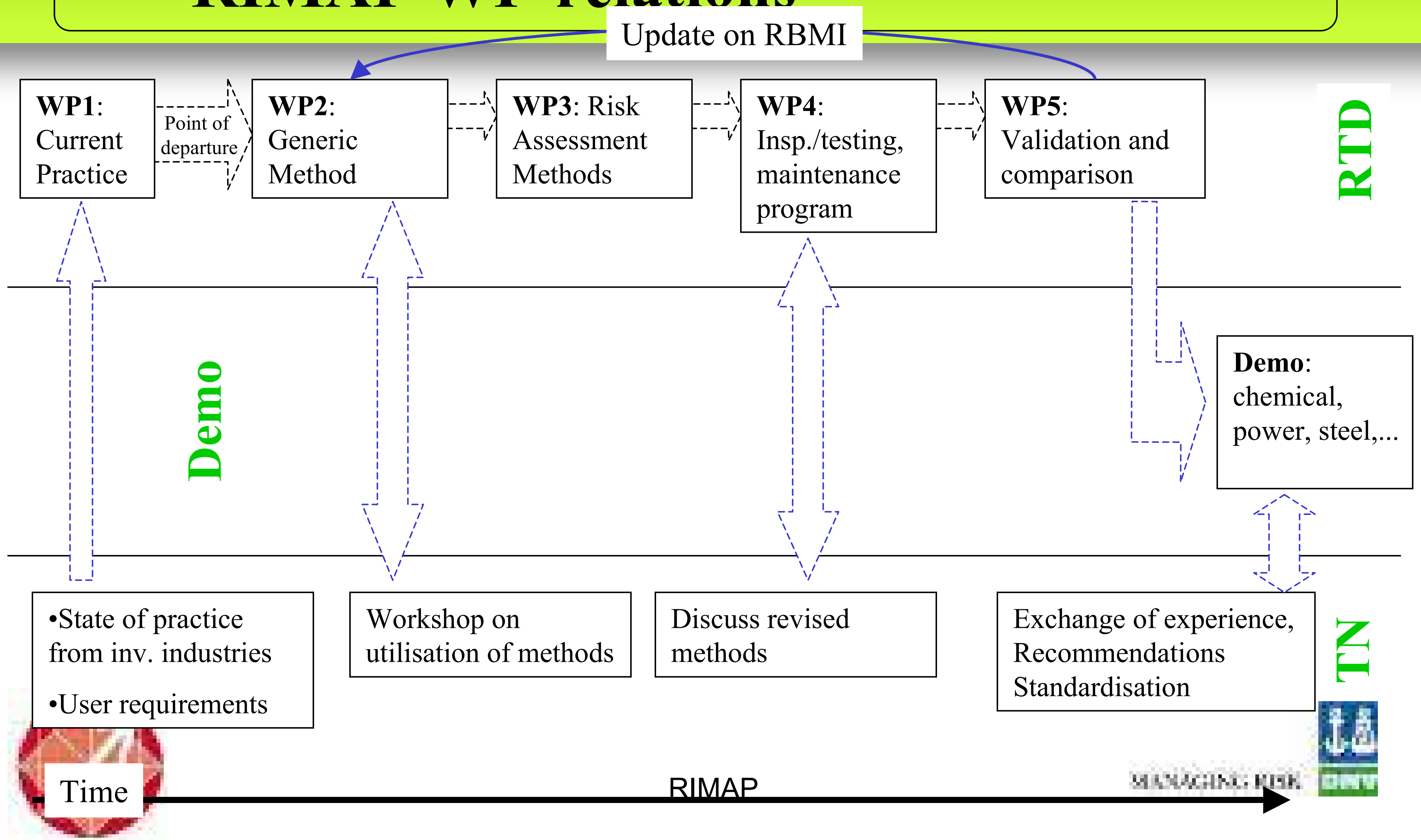
=> Scheduling program

RIMAP Demo: Demonstration

Per industry group:

- Petrochemical industry (Exxon & DNV)
- Power Industry (MPA, EnBW, Simens, ESB)
- Steel works (Corus)
- Chemical industry (Dow, Solvay, Hydro)

RIMAP WP-relations



RIMAP Innovation

- The integration of maintenance (RCM) and inspection (RBI) into a uniform decision process
- The use of probabilistic decision analysis for process systems
- Combining the theoretical modelling of plant failure ("hard" knowledge) with plant experience ("soft" knowledge)
- Technology transfer between industry sectors, i.e..

Goals & Benefits

For the plants/end-users:

- reduced operational and failure costs.
- a clear philosophy for planning

For the inspection companies:

- Tailoring of tools and methods
- know limitations

Regulators:

- basis to set proper requirements
- basis for standardisation

Consultants:

- enhanced services for the industry in particular during plant-networking and outsourcing.

RIMAP; Risk Based Maintenance and Insepection

- **Improved control of high risk failures - more attention to high risk components.**
- **Improve cost effectiveness of inspection resources**
- **Balance focus on safety and economical risk - current practice tends to focus on safety only.**
- **Documented and traceable program.**
- **Systematic use of experience data - basis for:**

CONTINUOUS IMPROVEMENT

2.5. D. Flotte, D. Chauveau, C. Boucher
Consolidation of practice of Time of Flight Diffraction method of non-destructive testing (TOFD) – New European project TOFDPROOF

- *Presentation*

CONSOLIDATION OF PRACTICE OF TIME OF FLIGHT DIFFRACTION METHOD OF NON-DESTRUCTIVE TESTING (TOFD) - NEW EUROPEAN PROJECT TOFDPROOF -

Didier FLOTTE
Daniel CHAUVEAU
Christian BOUCHER

THANKS

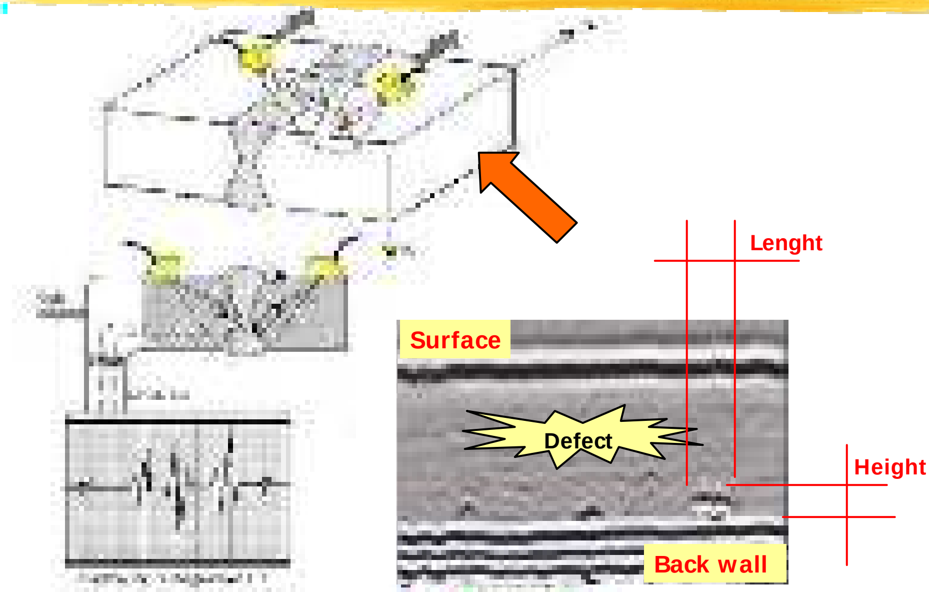
- Early contacts between Institut de Soudure and Stoomwezen (idea of the project)
- Expression of interest prepared for EC DG XXII within the framework of EPERC TTF3 and TG2 task group

MANY THANKS to :

TTF3 and TG2 members with special thanks to :

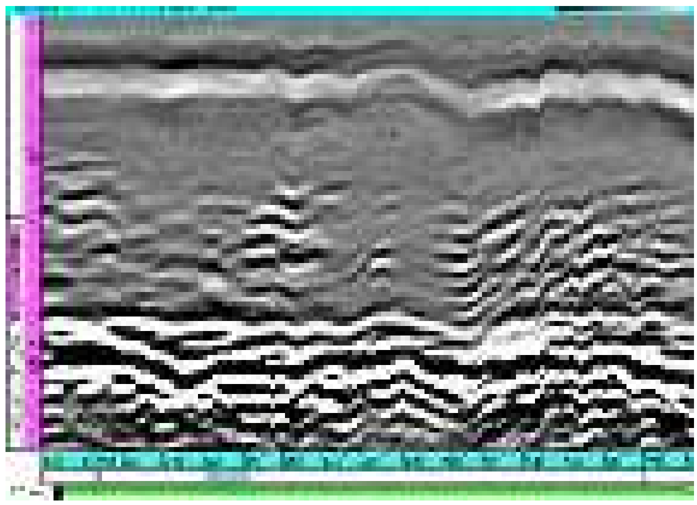
Guy BAYLAC and Erik ZEELENBERG

Time of Flight Diffraction Technique - Principle



TOFD PROOF Project

Time of Flight Diffraction Technique - Exemple of image



TOFD PROOF Project

THE CONSORTIUM

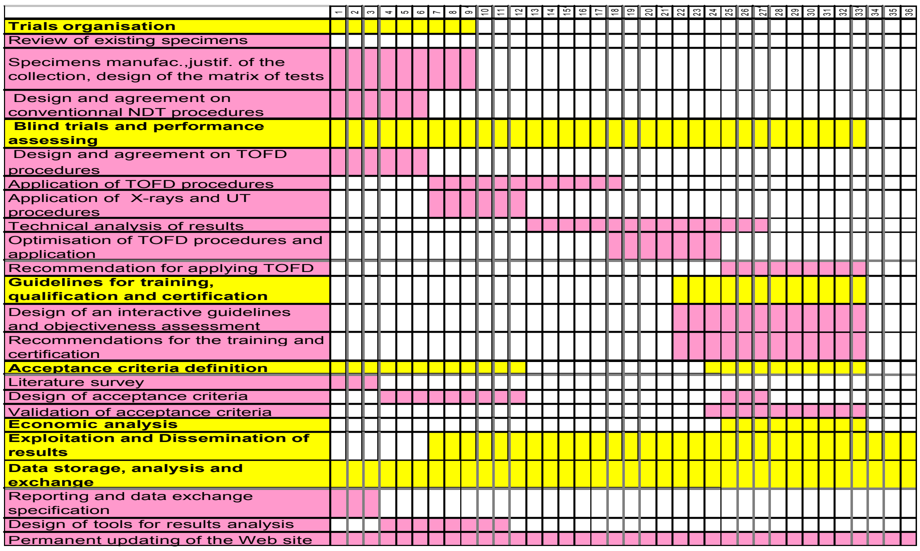
- Institut de Soudure (IS) (French welding institute) act as coordinator
- IS Service, a subsidiary of IS (France)
- Sonovation (Netherlands)
- TWI (Great Britain)
- Mitsui Babcock (Great Britain)
- MPA (Germany)
- Tecnatom (Spain)
- VTT (Finland)
- ISQ (Portugal)
- TÜV (Germany)

OBJECTIVES

- Compare TOFD performance with conventional NDT as applied according to the European standards
- Define the field of application of TOFD
- Optimise the methodology of application
- Verify the detection of transverse defects
- Develop acceptance criteria
- Define a framework for operators qualification and certification

WORK PLAN

36 moths duration



TOFD PROOF Project

page 7 - 10/00

WORK PLAN

Trials organisation

- Review of existing specimens
- New specimens, design and justification of the matrix of tests
- Design and agreement on NDT procedures

TOFD PROOF Project

page 8 - 10/00

WORK PLAN

Blind trials

- TOFD procedures agreement
- TOFD procedures application
- X-rays and UT procedures application
- Technical analysis
- Optimisation of TOFD procedures
- Set of recommendations

WORK PLAN

Guidelines

- Design interactive guidelines
- Recommendations for training and certification

Acceptance criteria

- Literature survey
- Acceptance criteria design
- Acceptance criteria validation

WORK PLAN

Data storage, analysis & exchange

- Design tools for results analysis
- Permanent updating web site

Exploitation & dissemination results

- **specific workshop**
- **Web site**
- **Permanent link with CEN - TOFD ad hoc group TC121**

TOFD PROOF Project

page 11 - 10/00

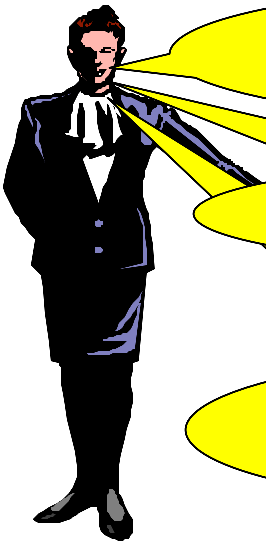
BENEFITS

- Producing a coherent package of E.U. agreed documents
  - procedures
  - acceptance criteria
  - recommendations for training and certification
- Use of TOFD as a standalone NDT technique for weld inspection
- Reduced fabrication and repair costs
- Quality and traceability improvement through digital recording and archive
- Reduced environmental damage (radiography replacement)
- Better personnel safety (no radiation risk)

TOFD PROOF Project

page 12 - 10/00

CONCLUSIONS



Coherent TOFD full package
available link with CEN

Technical efficiency demonstrated
with an European project

Assessment of cost
competitiveness compared with
conventional NDT

TOFD PROOF Project

2.6. C. Müller, M. Scharmach, L. Schaefer
Current status in the area of reliability of NDT: Experience in Europe and USA

- *Abstract*
- *Presentation*

CURRENT STATUS IN THE AREA OF RELIABILITY OF NDT: EXPERIENCE IN EUROPE AND USA

Christina Müller, Martina Scharmach
BAM Berlin, Germany

Lloyd Schaefer
FAA USA/Siemens Power Generation

Abstract

The state of the art of the reliability in NDT is based on the following definition elaborated during the second European-American Workshop on NDE Reliability held in Boulder, CO, USA, during September 1999: “NDE reliability is the degree that an NDT system is capable of achieving its purpose regarding detection, characterization and false calls. Where the NDE system consists of the procedures, equipment and personnel that are used in performing NDE inspection”. This guidance is especially of interest when inspecting for beginning of life and accumulated defects/degradation safety critical systems such as pressure equipment. Three different approaches to investigate the reliability of NDE signals will be described. The first approach, described as the performance demonstration, is preferred in the US American nuclear power industry. This is an integral consideration of the non destructive test as a system where the whole NDE system is packed in a black box and only the input in terms of the real existing flaws in the component is considered and compared to the output in terms of the indications of the human inspector or from an automated system. A more sophisticated approach to the performance demonstration – with a look inside the black box – is used to varying degrees within the American and European Aerospace industries: The “â versus a” approach, which considers the signal distributions caused by a certain configurations of flaws. The second approach - the predominant European method – relies on a standardized description of physical/technical parameters of the NDE system which are preconditions for successful system performance. The third approach - the modular conception - is a marriage of the first two and can be also considered as the scientific basis for the Technical Justification developed within ENIQ: The signal chain is cut into main modules. Each module is assessed in a most appropriate individual way e.g. via modeling calculations. The single results are joint together according to the reliability theory of systems where the reliability of the total system is composed of the reliability of the subsystems. Separating criteria for the system were proposed through a reliability formula developed during a series of European-American workshops on NDE reliability. Examples for the ROC /POD approach in terms of the investigation of the reliability of ultrasonic manual testing and for the modular approach in terms of the reliability investigation of radiographic testing will be presented. It will be strongly recommended to apply the ROC/POD and Modular Conceptions to the assessment and optimization of the NDT applied to European Pressure Equipment to provide an appropriate input for RBI and RBLM.

Current Status in the Area of Reliability of NDT: Experience in Europe and USA

Christina Müller, Martina Scharmach BAM, Berlin, Germany

Lloyd Schaefer PNDE USA/Siemens Power Generation

1. Background and Overview of the Approaches
2. Integral Approach: ROC - Reciver Operating Characteristic and its Relation to POD
3. Example 1: Reliabiliability Investigation of Manual Ultrasonic Testing
4. Modular Approach and Example 2: Radiographic Crack Detection in Tube Welds
5. Summary and Outlook

1. Background and Overview of the Approaches

Definitions: from the Second European American Workshop on NDE Reliability, September 1999, Boulder, Colorado, USA:

NDE System is the procedures, equipment and personell that are used in performing NDE inspection.

Reliability - NDE reliability is the degree that an NDT system is capable of achieving its purpose regarding detection, characterization and false calls.

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- EPERC Technical Task Forces 3,5 and 7 - 2001, October 5, 2001, Stuttgart, Germany
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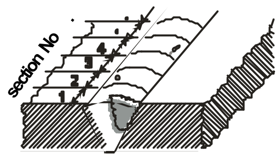
The Aim of NDE

NDE-System

Truth → Inspection Report



Section No.	1	2	3	4	...
Defect Type	Eb	Aa	-	Ab	
Importance	3	1	-	1	

1 acceptable flaw
2 indifferent / additional radiography
3 unacceptable flaw

Describe the real status of a component

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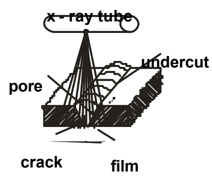
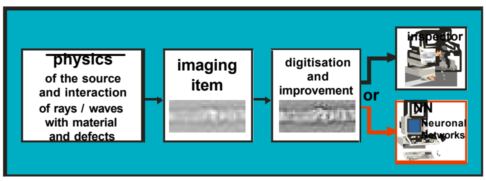
The Signal Transfer Chain of the Radiographic System

environmental influence





social and psychological influence

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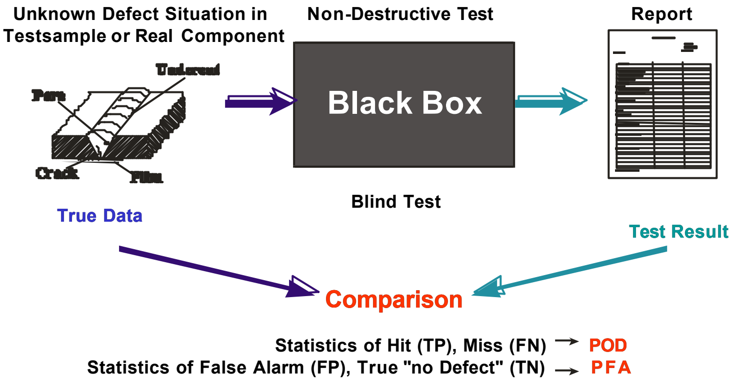
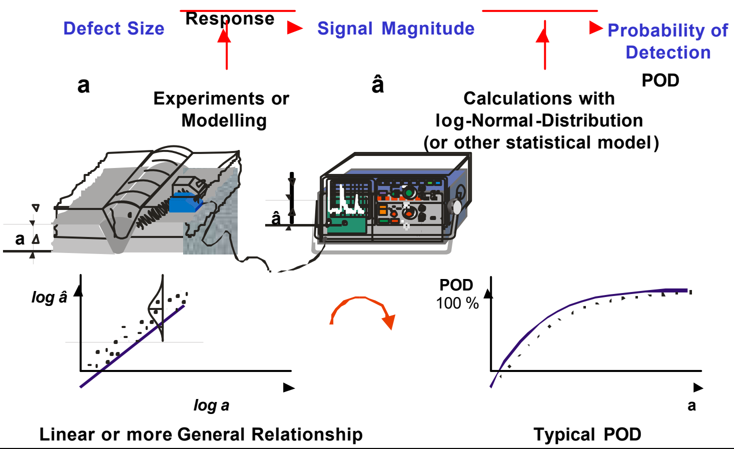
Principle of a „Performance Demonstration“



„â versus a“

For automated thresholding systems a forecast of the POD is possible from the statistics of the Response Signals



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Combination of the individual Factors within a modular Approach

European-American Workshops:

1997, Berlin, Germany, BAM
1999, Boulder; Colorado, USA, NIST

Reliability Formula

$$R \equiv f(IC) - g(AP) - h(HF)$$

Total Reliability of an NDE System.

Intrinsic Capability of the sytem driven by physical laws and technical potential generally considered as an ideal upper bound.

The effect of human factors, often further reducing the capability of the NDE System.

The effect industrial of application parameters, such as access restrictions, surface state, generally reducing the capability of the ideal NDE System.

2. Integral Approach: ROC - Reciver Operating Characteristic and its Relation to POD

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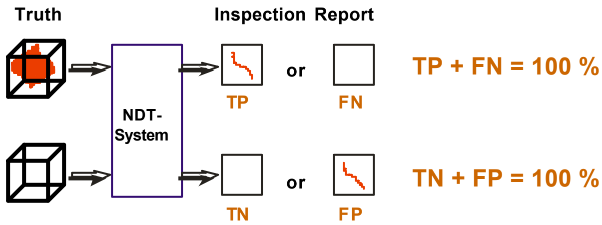
The Principles of ROC (Reciver Operating Characteristic)

Four Possible Diagnosis Results in NDT



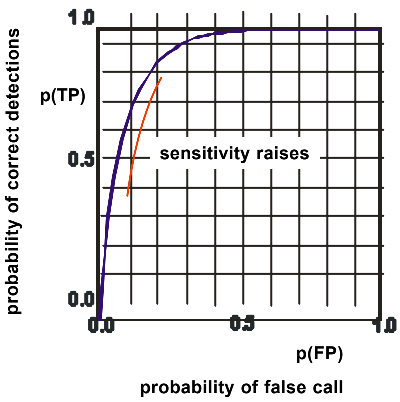
TP: true positive indication (hit)

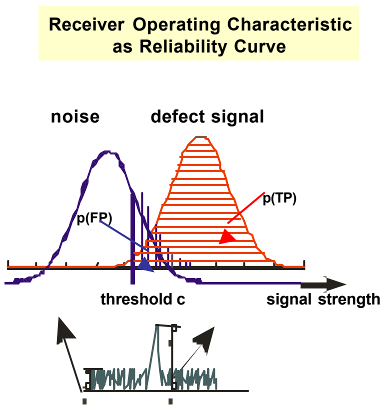
FN: false negative indication (miss)

TN: true negative indication (correct "no defect")

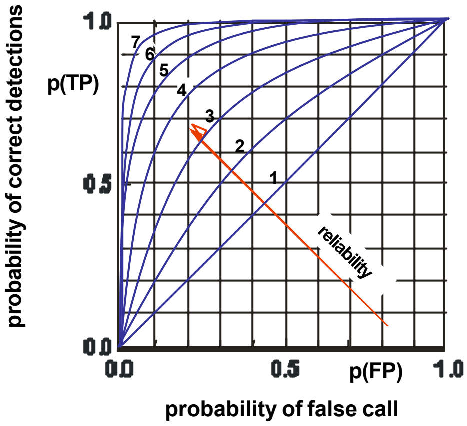
FP: false positive indication (false alarm)

Characteristic of one NDT - System Theory





Comparison of Different NDT - Systems



Standard Deviations for all Curves

Noise : 1.0
Signal : 1.0

Meanvalue of Noise : 0.0

Difference of the Mean Values
Signal - Noise :

1 - 0.0
2 - 0.5
3 - 1.0
4 - 1.5
5 - 2.0
6 - 2.5
7 - 3.0

Increasing Reliability

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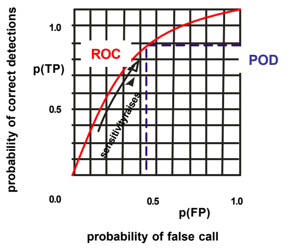
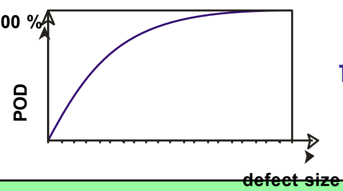
ROC - POD Relation
POD - Probability of Detection



- POD and ROC have the same statistical background but arranged with respect to different variables
- Regarding one point on the ROC - curve for a fixed false call rate (fixed by system sensibility)
- Determination of POD values for different defect sizes

Defect Detection Rate for a Large Number of Experiments = "Probability of Detection"



Typical POD Curve

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3. Example 1: Reliabiliability Investigation of Manual Ultrasonic Testing

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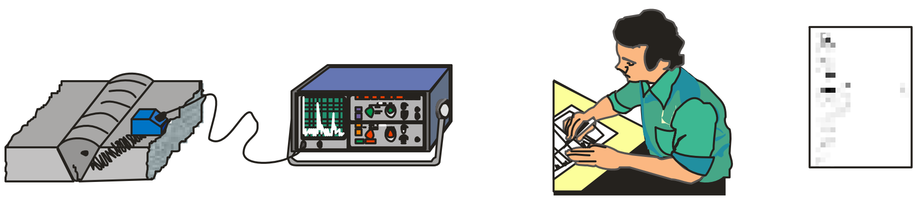
Example Testing System for Ultrasonic Manulal Testing



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Outline of Experiments

Ultrasonic Manual Testing: *Human Factor*

Welds typical for the railway field

348 artificial defects of type , and different sizes

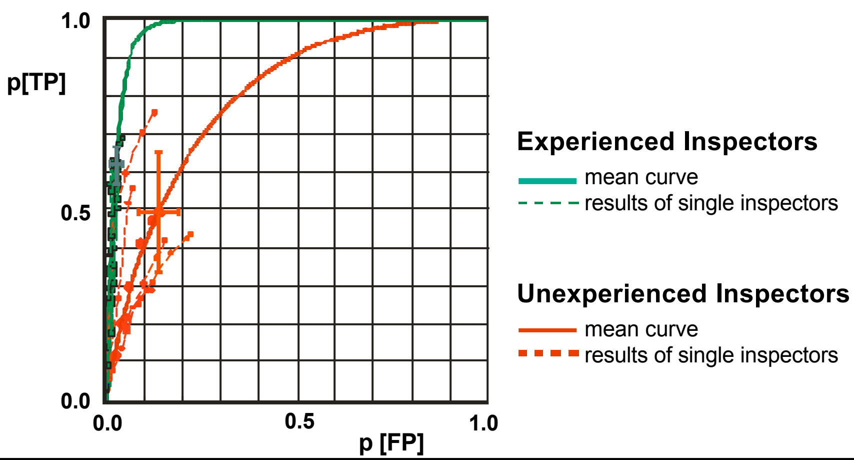
50°, 65° ultrasonic probes

Detectability ***very good, good, middle and bad, very bad***
according to quantitative threshold levels with 6 dB distance

Grading units 3 cm

5 unexperienced Inspectors (immediately after training)
5 experienced Inspectors (>10 years)

Results from Statistical Reliability Investigation (ROC)



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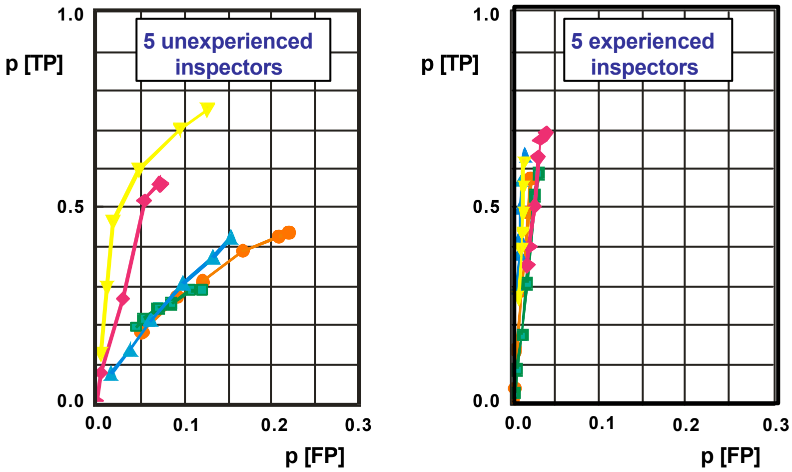
Results from Statistical Reliability Investigation (ROC)



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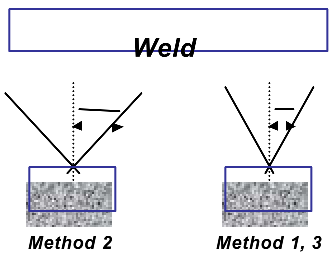
New Investigation

Method 1 Probe: 2,5 MHz
source receiver size: 12 x 18 mm
Angle: 50°, 65°
Device: UD2-12 (3 Inspectors)
divergence angle 6,2°

Method 2 Probe: 2,0 MHz
source receiver size: 8 x 9 mm
Angle: 45°, 70°
Device: DIO (2 Inspectors)
divergence angle 11,8°

Method 3 Probe: 2,5 MHz
source receiver size: 12 x 18 mm
Angle: 50°, 65°
Device: DIO (2 Inspectors)
divergence angle 6,2°

The first difference between the methods is the beam divergence angle, the second the device



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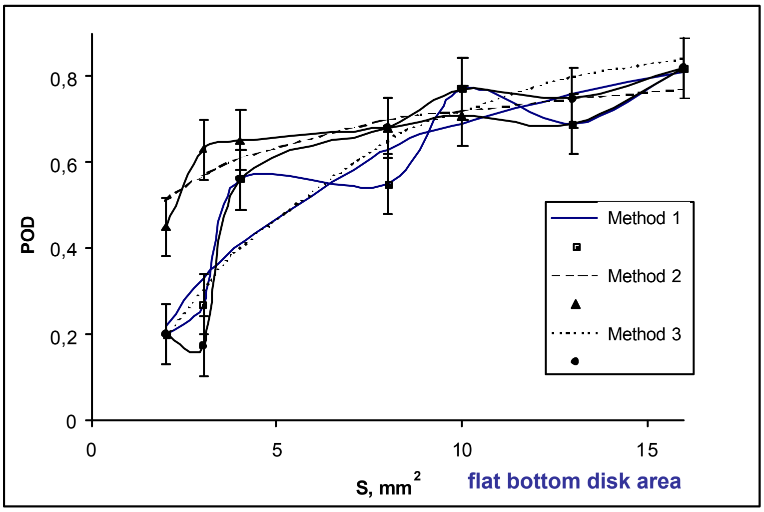
POD - Results



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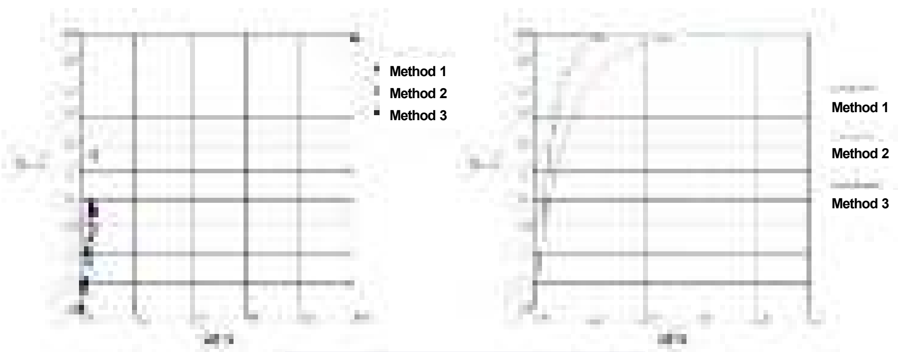
ROC - Results



	p(TP)	p(FP)
Method 1	0,36	0,05
Method 2	0,56	0,05
Method 3	0,39	0,04

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4. Modular Approach and Example 2: Radiographic Crack Detection in Tube Welds

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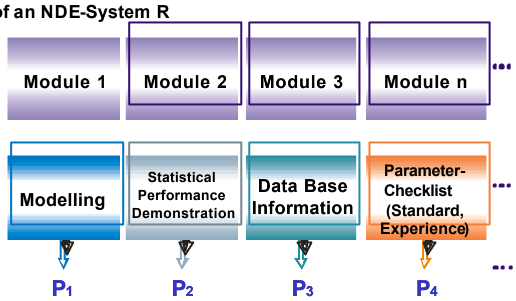
Modular Validation - Application of the Reliability Theory of Systems Set up Scientific Basis & RULES for the Technical Justification

1. Task: Determine the Reliability of an NDE-System R

2. Cut the NDE- System into Main Modules

3. Determine the Contribution of the Modules to R: Various Possible Methods of Determination of the Reliability of each of the Modules



4. Join the Contributions of the Modules together according to the Reliability Theory of Systems to form R

$P_{tot} = R(P_1, ..., P_n)$ R: Function According to the Reliability - Theory of Systems.

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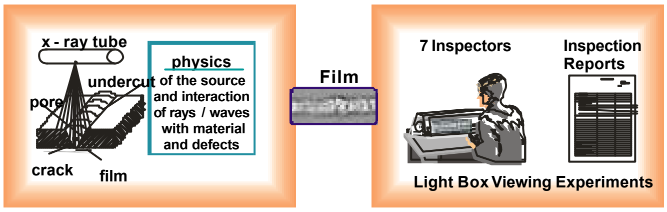
Example:
Radiographic Crack Detection in Tube Welds

(thermal induced cracks in ferritic tube welds, in-servic inspection)

Module 1: IC | **Module 2: AP+HF**



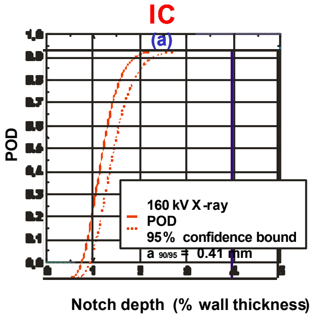
Modelling Calculation ⇓ POD_1

Crack Detection Statistics ⇓ POD_2

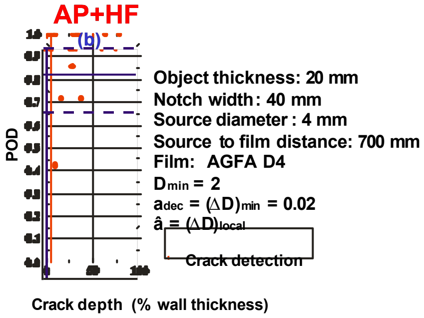
$$P_{TOT} = \underbrace{POD_1}_{IC} * \underbrace{POD_2}_{AP+HF}$$

Example:
Radiographic Crack Detection in Tube Welds

(thermal induced cracks in ferritic tube welds, in-servic inspection)



(a) Theoretical POD : "â versus a" from simulated notch experiment (Modelling POD)



(b) Experimental results of film interpretation (mean of seven inspectors)

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5. Summary and Outlook

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Summary and Outlook

The determination of the reliability of NDE signals is a complex and effortive task but in any case worthwhile not only to assure efficient and reliable NDE-procedures especially for the testing of pressure equipment but also to provide quantitative input to RBI and RBLM. The first step is to define the essential technical parameters of the system. The ROC and POD methods are appropriate tools to provide a clear measure of integral performance of the system though it has to be paid by high effort in test series with realistic test samples. The modular approaches yield a more efficient way not only to measure but also to optimize the reliability of the NDE systems. We propose to apply the ROC, POD and Modular Conceptions as part of RBI and RBLM in an optimized manner to be developed for the European Pressure Equipment Industry.

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3rd European-American Workshop on NDE Reliability

11. - 13. September 2002, Berlin, Germany

Special Topics:

- Check of the Reliability Formula with real examples and hypothetical case studies from different sectors of industrie
- Actual problems on creating POD‘s ROC‘s
- Submission of abstracts for papers or workshop teachings until January 2002 to Christina.Mueller@bam.de

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3rd European-American Workshop on NDE Reliability

Reliability Formula

$$R \equiv f(IC) - g(AP) - h(HF)$$

Which components contribute to R?

$$P_{tot} = \Im[P_{IC}, P_{AP}, P_{HF}]$$

Which mathematical formulation for the combination of the components?

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2.7. P. Auerkari, A. Jovanovic: Reliability of NDE as a factor of risk-based life management and a topic of future work in EPERC

- *Abstract*

Performance of NDT - with examples on surface inspections for gas turbines

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Aleksandar Jovanovic

MPA Stuttgart, Germany

Abstract

The performance of non-destructive inspections is often described based the probability of detection (POD) for a given defect size and type. It can be argued that potentially even more important parameter for this purpose is the probability that an observed defect indication - classified as a defect - indeed is an unacceptable (reportable) defect. This conditional probability of detection is affected by the probability of false calls (FCP) and defect density so that increasing FCP and decreasing defect density increase the limiting size of the correctly classified defect.

This effect is significant, when for example the structure is in good condition or when the largest defects are close to the limiting detection capabilities of the inspection process. An example has been taken from surface inspection of gas turbine components. In these inspections the defect size that can be reliably discerned can be markedly larger than the size limit estimated from a simple POD criterion (e.g. 90% POD). However, relatively high defect density is often characteristic to initiating fatigue and thermal fatigue cracking in gas turbine components, and this reduces the observable defect size.

Maintenance based on defect tolerance requires good quality inspections, particularly when growth of defects will limit life. Improved performance in the observed minimum defect size can be used to extend the periods between inspections.

1. Definitions

The terms, abbreviations and definitions used below are shown in Table 1.

Table 1. Symbols, abbreviations and definitions.

Abbreviation	Quantity	Definition
a	Defect size	Length of defect on surface
a_c	Resolution limit	Smallest discernible defect size
D	True defect density	D = defective inspected / all inspected items; or D = defective / all inspected surface or volume elements
D'	Estimated defect density	As D, but estimated using NDT
FCP	False call probability [1)]	FCP = shown false calls / all reportable defects; or FCP = incorrect defective / all defective items
NDT	Non-destructive testing [2)]	Inspection using (usually standard) non-destructive methods
POD	Probability of detection	POD = no. of observed reportable defects / no. of all reportable defects; or POD = no. of items observed to be defective / no. of all defective items
PT	Penetrant testing	Surface inspection using the PT method
R	Reliability of inspections	Probability that the inspection result complies with its requirements [3)]

1) also FCR (false call rate), PFA (probability of false alarm); p(FP) (probability of false positives); PFI (probability of false information)
2) also NDE (non-destructive evaluation) or NDI (non-destructive inspection)
3) probability that the NDT system (method, equipment and personnel) complies with the defined objectives regarding defect detection, characterisation and false calls.

2. NDT of gas turbines

Visual inspections (including videoscopy, endoscopy and dimensional measurements) and surface inspections are by far the most common NDT techniques applied for gas turbines, particularly in the field. Surface inspections involve mostly penetrant testing (PT), and to some extent eddy current testing (ET). Some of the advantages and limitations of these techniques are shown in Table 2.

Table 2. Features of common NDT techniques for gas turbines.

Technique	Advantages	Limitations
Visual inspection	Inspection speed	Resolution, surface only
Endoscopy	Internal inspections	Geometry, resolution, surface only
Penetrant testing	Inspection speed	Surface only
Eddy current	Insensitive to surface quality [1)]	Strict calibration requirements
Dimensional	Shows dimensional change	Reference required, surface only

1) to some extent also for internal defects

In the usual inspection conditions in the field during overhauls, fundamental quality requirements include specified calibrations, compatibility to inspection standards and other requirements, as well as competence and reference of the party providing inspections. However, even with formally qualified inspection personnel and standard methods of NDT, inspection results typically show considerable scatter (Lahdenperä 1989, Rummel & Matzkanin 1997). The reasons for this scatter are partly technical and partly human in origin. In all cases the measurements have a characteristic resolution, and smaller signal than this limit cannot be resolved from background noise. However, the limit is diffuse so that for each signal level (defect size) corresponds to a certain probability of detection (POD), which is widely used as a parameter to describe the performance of inspections (Rummel 1989, Lahdenperä 1989, Crutzen 1991, Connolly 1995).

Here, the effect of scatter factors (uncertainty) of surface inspections are considered from the point of view of probability of detection and reliability of the inspection results.

3. Modelling the key figures for NDT performance

Key figures for NDT performance include probability of detection (POD) and false call probability (FCP). These are essentially defined in Table 1. The POD for both definitions depends on the criteria for reportability or defectiveness. Usually these criteria are given as defect size or a signal level proportional to it.

A common model for the dependence of expected POD on the defect size a is

$$POD(a) = POD_{max} \{1-\exp[-((a-a_o)/\beta)^m]\} \quad (1)$$

where POD_{max} is the maximum level of POD and a_o (≥ 0), β (≥ 1) and m (≥ 1) are distribution parameters to be fitted from the inspection results. The functional shape of (1) is due to the fact that largest defects of a given component or structure are those of most interest, and fortunately these are also generally easiest to detect. From the reliability point of view, the most important defect is not the smallest defect that has been observed but the largest defect not detected. The equation (1) is an extreme value distribution of the largest defects (Gumbel type III, or three parameter Weibull distribution).

The defect size limits may be set at 50 - 80% of POD for ordinary purposes, but for gas turbines often either at the mean or 95% lower confidence line level of 90% POD location (90/50 or 90/95-

values). Acceptable defect sizes are naturally not dependent on the inspection techniques but rather on the limits set by design or standards.

For the probability of false calls and its dependence on the defect size a, one of the most common models is a Weibull distribution of the form

$$FCP(a) = FCP_{max} \exp\{-[((a-a_1)/\beta_1)^{m'}]\} \qquad (2)$$

where PF_{max} is the maximum level of FCP, and a_1 (≥ 0), β_1 (≥ 1) and m' (≥ 1) are again distribution parameters to be fitted from test results. Normally one can assume that at the resolution limit (a_c) $FCP_c = 0.5$, because at this limit an indication can be assumed real or false at an equal probability. The defined resolution limit is at a point where the measured signal just emerges from the background noise in the whole chain of measurement rather than from the signal to noise ratio of the measuring equipment. With decreasing defect size, the measured defect indication is a false call at an increasing probability.

As limit values	$POD \rightarrow POD_{max}$ (≈ 1)	when $a \rightarrow \infty$
	$POD \rightarrow 0$	when $a \rightarrow 0$
	$FCP \rightarrow FCP_{max}$ (≈ 1)	when $a \rightarrow 0$
	$FCP = FCP_c$ ($\approx 0{,}5$)	when $a = a_c$
	$FCP \rightarrow 0$	when $a \rightarrow \infty$

The expected dependence of POD and FCP on defect size is shown in the examples of Figs 1 and 2 for manual and automated penetrant testing. To determine POD and FCP experimentally is relatively tedious even for a single NDT-method and component type. However, some examples have been published also for surface inspections of gas turbine components (Rummel & Matzkanin 1997).

Usually POD and FCP are determined from test samples with known artificial defects. These samples can be classified according to correctly detected, not detected and falsely classified defects. With sufficient repeats of inspections and sufficient number of defects, POD, FCP and their confidence limits are obtained for each defect size. In practice FCP is usually about 1-5 %, while POD should generally be more than 50%. To determine FCP requires more experimental work than POD, and FCP is much less frequently available.

The effective probability of detection can be defined as probability (PD) that the indicated defect really is defective, or

$$PD = D \cdot POD / [D \cdot POD + (1-D) \cdot FCP] = 1 / [1 - (1 - 1/D) \cdot FCP/POD] \qquad (3)$$

where D is the true defect density, or

D = defective inspected / all inspected items

or D = defective inspected / all inspected surface (volume) elements

In the ideal extreme FCP = 0 (or D = 1), and then PD = 1 or all reported defects are real. In practice usually FCP > 0 and $0 < D \ll 1$, and then PD(a) resembles the POD(a) curve but remains usually below it. The defect size corresponding to the conditional probability of detection PD (e.g. 90%) is larger than the defect size corresponding to the same level of traditional POD. The difference between the defect sizes corresponding to of PD and POD increases with increasing FCP and decreasing D.

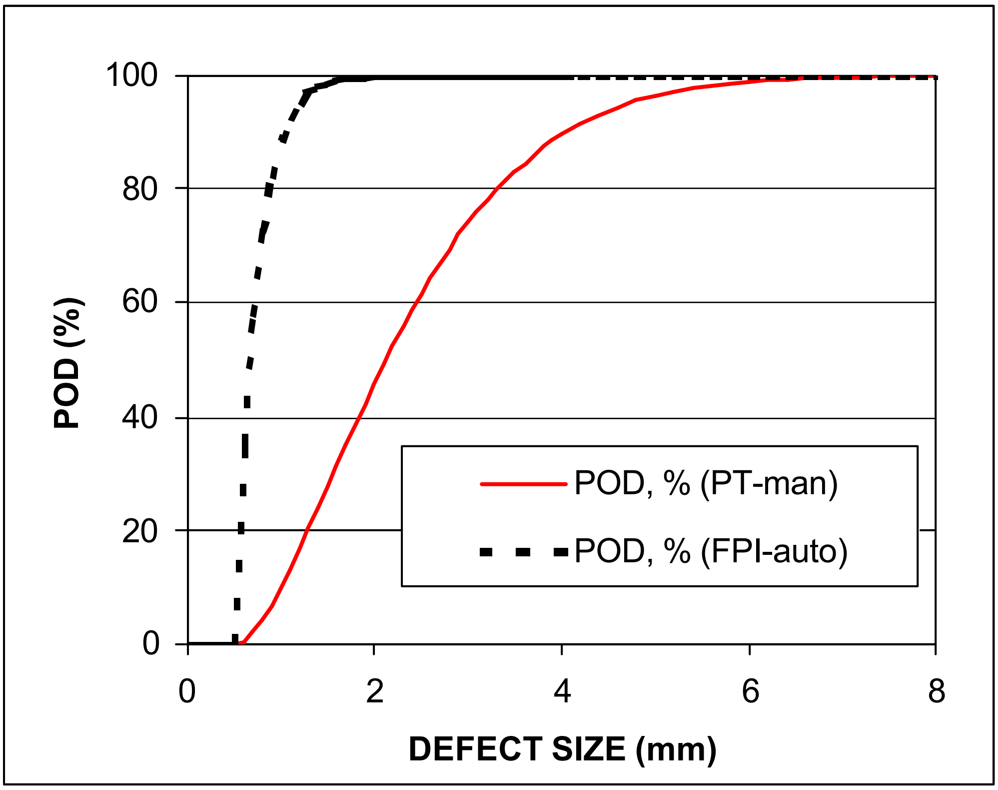

Fig 1. POD as a function of defect size. In the example (POD_{max} = 100 %, a_o =0.5 mm) the lower line corresponds roughly to common manual inspection, and the other line to automated fluorescent PT (Adair & Kindrew 2000). The lines correspond to 90% POD level (50% confidence line), for 1 mm (automated) and 4 mm (manual) defect size.

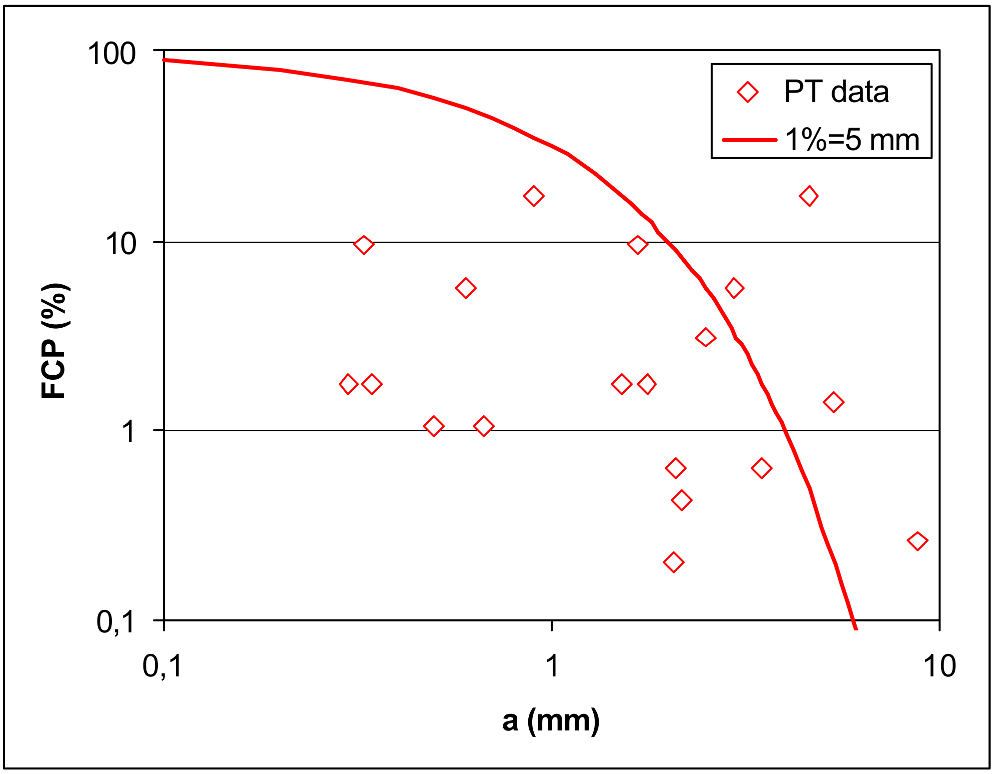

Fig 2. FCP in fluorescent PT (data Rummel & Matzkanin 1997) The line corresponds to equation (4) with FCP = 1%, when a = 5 mm.

The natural expected defect density is for many defect mechanisms a function of the defect size, and can be assumed to be Weibull distributed similarly to FCP (Schuster et al 1998) so that

$$D(a) = D_{max} \exp[-(a/\beta_2)^n] \qquad (4)$$

where β_2 (> 0) and n (>0) are fitted parameters of the distribution. As limit values (Fig 3)

$$D(a) \rightarrow D_{max} (\approx 1) \qquad \text{when } a \rightarrow 0$$
$$D(a) \rightarrow 0 \qquad \text{when } a \rightarrow \infty$$

On the other hand, the defect density estimated by NDT (Schuster et al 1998)

$$D'(a) \approx POD(a) \cdot D(a) \qquad (5)$$

where D(a) is the real defect density. Then from (3)

$$PD(a) = 1 / \{1 + [(1/D'(a))-(1/POD(a))] \cdot FCP(a)\} \qquad (6)$$

The true defect density is not known, but the observed defect density from the NDT results will provide an estimate.

Fig 4 shows the conditional probability of detection for three cases in surface inspections of a row of gas turbine blades (of 100 blades, either 2 or 50 show reportable defect indications; i.e. D' ≈ 2 or 50 % or sets according to the defect sizes). POD(a) and FCP(a) have been assumed as in Figs 1 and 2.

If the defect density is high, (more than about 50%), PD(a) is usually above the basic POD curve. Then the defects are found relatively easily, and that the indicated defects are increasingly likely to be real. Even if all defects were not detected, as the corresponding POD is at a lower level, the consequences will also depend on the coverage of the inspections. Low defect density can markedly increase the limit size that will be detected at a given probability (e.g. 90%).

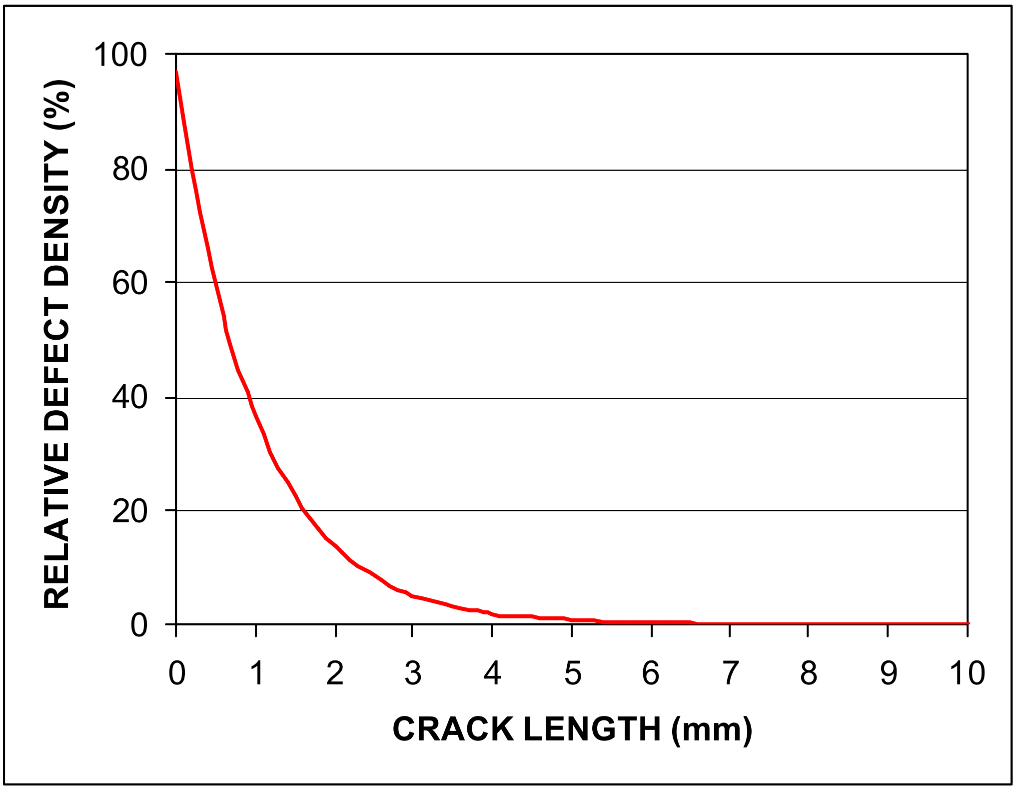

Fig 3. Expected dependence of defect density on defect size. True dependence varies, but often follows approximately the curve within some range of defect sizes.

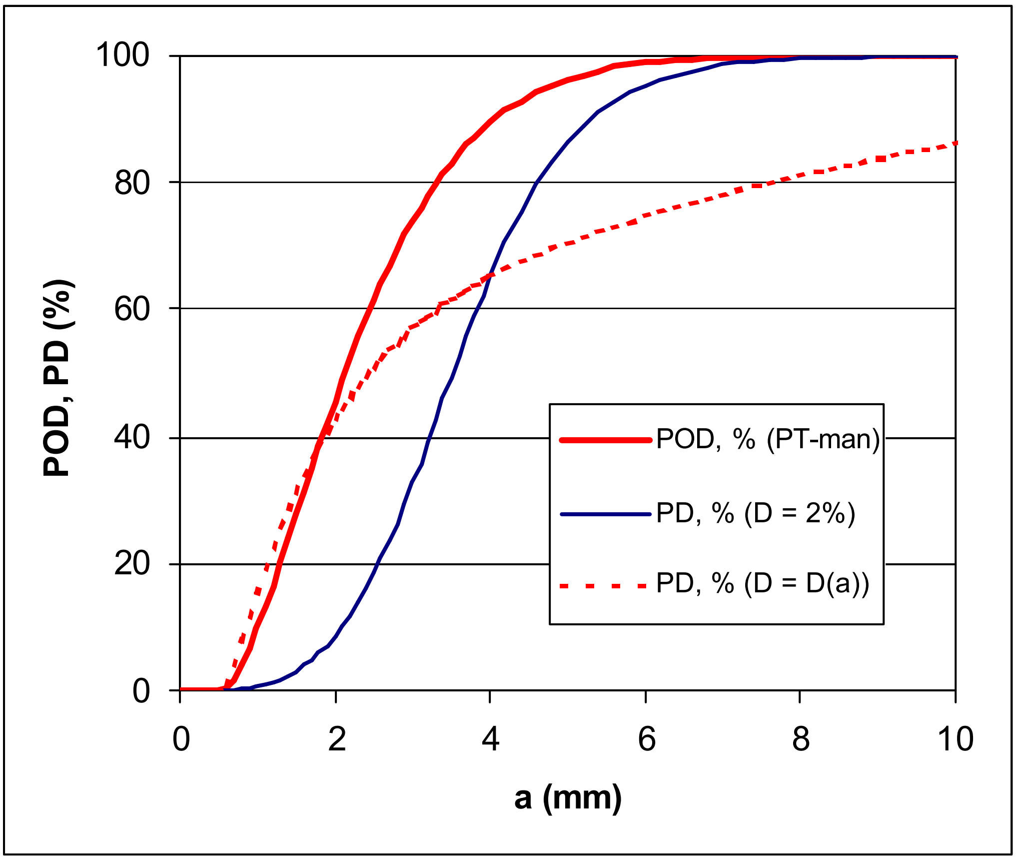

Fig 4. Conditional probability of detection PD in comparison with POD(a), when FCP(a) is as in Fig 2 and defect density is either constant (2%) or as given by the equation (4).

4. Defect acceptance

The acceptable size of the defects sought and characterised by NDT:n depends on the inspected item and the purpose of the inspections. The purpose may be e.g. testing for acceptability after manufacturing or reconditioning, acceptance testing at the time of delivery or testing for condition assessment after a period of service.

Certain components, such as vanes or heat shields of gas turbines, may tolerate quite large defects, but heavily loaded regions of the rotating blades (buckets) only very small ones. In principle reliable characterisation of small defects can be an advantage, when the aim is to predict the need for reconditioning or change well before the forthcoming overhauls/inspections.

In small gas turbines like aircraft engines, both the components and the defect sizes of interest are small. This is partly due to short distance (ligament) for crack growth in small parts, and partly because of lower additional defect tolerance from the manufacturing limits than for of larger power plant turbines. On the other hand, increasing component size means more volume to be inspected, and thereby additional requirements for the reliability of inspections. E.g. internal inspections may also invoke limits from accessibility.

Two main principles have been used for designing the turbine life. The older of these corresponds to conventional fatigue design, and assumes that new material includes no defects but only scatter in material strength, giving the design value of stress/strength (e.g. mean strength minus 3 x standard deviation). Then NDT is only an auxiliary tool of quality control, with no use for the detailed information on the defects or defect sizes. A newer design principle is the damage tolerance approach (DTA). This assumes that all critical locations include a defect which at the time of inspection (in case larger size is not indicated) is exactly at the detection limit. The inspections and operational monitoring aim to prevent unwanted growth to critical size between periods of inspection. This principle requires good quality inspections at maximum operational periods that correspond to a half of the expected life from the defect growth rates. The approach also requires detailed information on the performance of NDT. Life management from these principles is also called inspection based life management, or retirement for cause (RFC).

According to the damage tolerance principle, it is an advantage to detect reliably also very small defects, as long as they are characteristic to the component. In some components of aircraft engines, such as turbine disks, this can translate to so small defects (0.1 x 0.3 mm) that they are not detected using the traditional manual surface inspection methods, and may require e.g. automated eddy current testing. Reported advantages include lower cost, increased life by a factor of 2, improved availability, lower failure rates and lower need for spare parts (Pairazaman et al 2000).

5. Performance of NDT

The results can be compared with typical criteria on the nominal defect size criteria for gas turbine blading. Typically, the maximum allowed defect size for the critical blade (bucket) regions after e.g. repairs is of the order of 0.4 mm (although a zero limit is frequently claimed). Based on the above analysis, smaller defects than this are clearly difficult to detect or interpret correctly in ordinary surface inspections.

However, the allowable defect size is frequently well above 10-20 mm in vanes (nozzles or stationary blades) of gas turbines. Hence the surface inspections should be well suited for most surface defects of vanes.

From inspection technique point of view, defects are likely to be detected, when POD is at least 90% (at 95 confidence level) and FCP does not exceed 3% (Tober & Klemmt 2000). Even beyond these limits, defect density can affect the corrected POD but particularly when the resolution is good, the natural defect initiation and growth mechanisms are helpful. For example, small fatigue cracks (less than 0.05 - 0.5 mm) grow faster than larger cracks, and many small cracks tend to initiate before one of them exceeds the next level of limits growing much faster than others. This results in increasing defect density when the defects are relatively small, or when POD is low and FCP relatively large. In thermal fatigue of gas turbines the same phenomenon works with larger defect size (1-10 mm), with the result that defects are found more easily when using traditional surface inspection.

Naturally there are other factors that are important for the reliability of inspections. One of these is involved in calibration of the inspection method. Ideally the calibration defects are made or selected with corresponding materials, geometry and defetcs with the inspected item, so that the limiting range of defects sizes are included. In practice, compromises are common particularly for cracklike defects.

"Inherent" reliability of NDT can be taken to be of the form

$$R = f\,[AC, HF] \leq IC \qquad (7)$$

where AC (applied capability) describes the actual technical performance of the method, equipment and NDT process, and HF (human factors) is related to the NDT personnel. IC (ideal capability) is the ideal or best physical performance for the applied method and technology. This performance is generally not achieved in practical inspections.

For the overall reliability of inspections that samples a larger set of components or areas,

$$R \sim \Sigma[P_T(i) \times D_i \times POD_i] \qquad (8)$$

where

$P_T(i)$ = probability that area or item (i) is inspected

D_i = density of reportable defects for the area or item (i); and

POD_i = probability of detection for reportable defects for the area or item (i).

The sampling capability of the inspection program will directly influence the credibility of the inspection results. It should be noted that at different locations the actual probability of occurrence of the defects, as well as their influence will vary case by case. When these can be assessed, the overall cost function or risk can be optimised by balancing the levels and and coverage of inspections. True risk assessment would include both the probability and cost of the unwanted events. The risks tend to be relatively high for gas turbines in comparison with other major equipment in power plants (Fig 5).

Features of the current status of development for the purposes of risk analysis, damage evaluation and approximate NDT performance are outlined for gas turbine examples in Table 3 to 5.

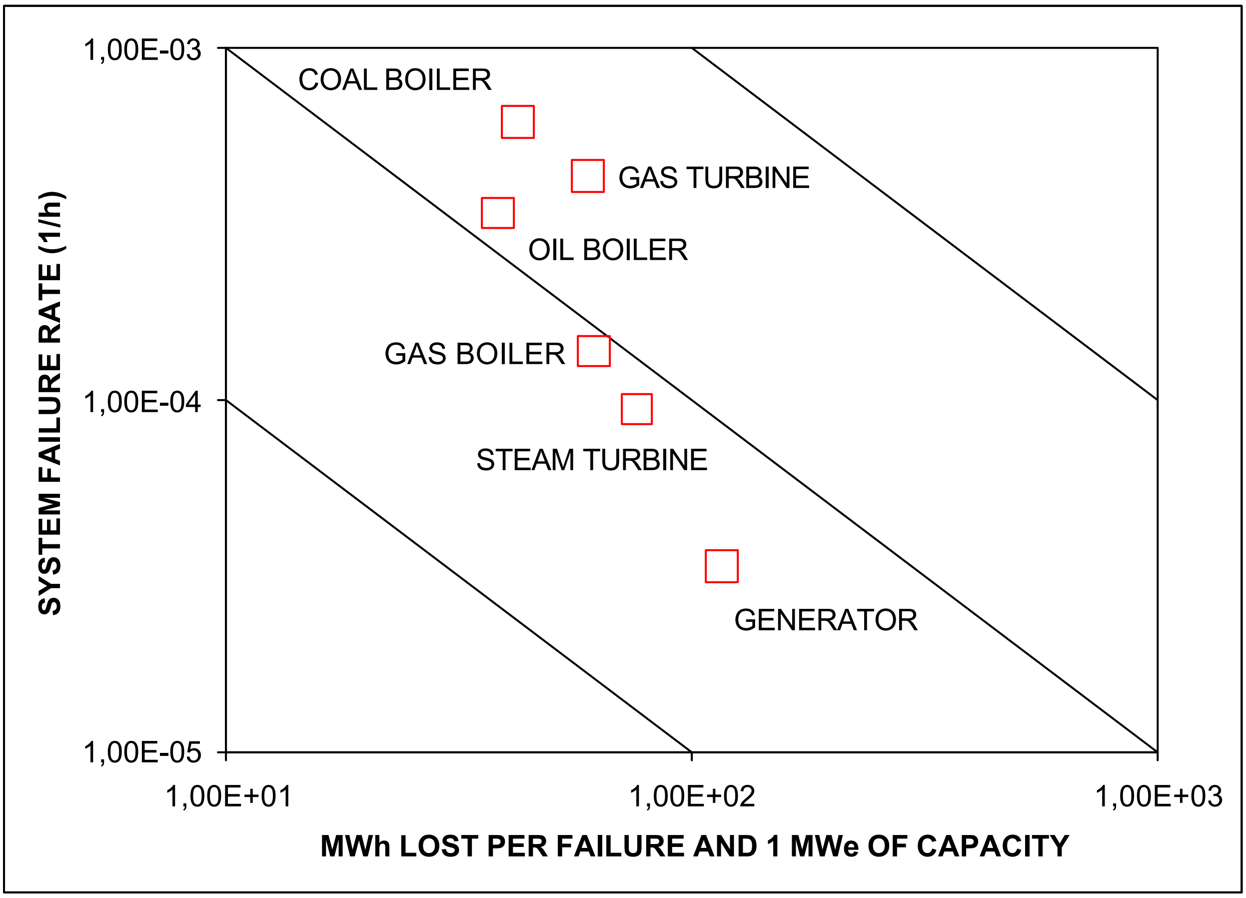

Fig 5. Relative risk of lost production due to failures in gas turbines and other components of power production. Descending lines correspond to constant relative risk (adapted from [12]).

Table 3. Current availability of evaluated NDT data as input for RBI / RBLM

Action point	US industrial	Aerospace	EPERC
Test results	√	√	Limited availability
Standard evaluation methods	√	√	?
Evaluated POD's etc	√	√	?
Catalogues of data	√	√	Not available
Input for RBI/RBLM	OK	OK	Missing

Table 4. Classification of type of damage vs. components in gas turbines.

Type of damage	Damage specifics, damage mechanism	Fossil plant: gas turbine
I. Environment related damage, leading to:		
Volumetric loss of material on surface (e.g. thinning)	General corrosion, oxidation, erosion, wear	Turbine & compressor blading, combustor, hot ducts
	Localized corrosion (e.g. pitting)	Turbine & compressor blading
Cracking (on surface, mainly)	Stress corrosion	-
	Corrosion fatigue	Turbine & compressor blading
Material weakening and/or embrittlement	Thermal degradation (coarsening etc.)	Combustors, turbine blading, transition ducts
	Embrittlement (incl. growth of brittle phases)	Turbine disks & blading, turbine blade coatings
II. Mechanical or thermomechanical, leading to:		
Strain, dimensional change	Overloading, creep, handling damage, FOD	Turbine & compressor blading, seals, bolts
Wear	Sliding wear, rubbing wear	Blade tips, seals, combustor and duct connections
Microvoid formation	Creep, creep-fatigue	Hot end turbine blading
Microcracking, cracking	Fatigue, thermal fatigue/ shock, creep, creep-fatigue	Disks, blading, combustors, burner rings, ducts, seals, bolts
Fracture, rupture	Overloading, FOD, brittle fracture	Turbine & compressor blading

Table5. Classification of damage vs. methods of inspection (data: Rummel & Matzkanin 1997)

Type of damage	Damage mechanism	Selected method 1)	POD for defect size of or size for		
			1 mm	3 mm	90% POD
I. Environmental damage, leading to:					
Volumetric loss of material on surface (e.g. thinning)	General corrosion, oxidation, erosion, wear	*UT*	30÷70%	50÷90%	2 mm
	Localized (pitting or other) corrosion	*UT*	30÷70%	40÷90%	2 mm
Cracking (mainly on surface)	Stress corrosion	*ET*	1÷85%	40÷90%	4±2 mm
	Corrosion fatigue	*UT*	8÷96% 2) 86÷98% 3)	50÷99% 4) 95÷99%,	3±1 mm 5) 0.8±0.4 mm ,5)
Material weakening and/or embrittlement	Thermal degradation (coarsening etc., incl. incipient melting)	*MeT*	~100% POD for cracks > 1 mm, about 90% POD crack ca. 0.05 mm		
	Embrittlement (incl. growth of brittle phases)	*MST*	*na*	*na*	*na*
II. Mechanical or thermomechanical, leading to:					
Strain / dimensional changes	Overloading, creep, handling damage	*DiM*	*na*	*na*	*na*
Wear	Sliding wear, cavitational wear	*DiM*	*na*	*na*	*na*
Microvoid formation	Creep, creep-fatigue	*MeT*	*na*	*na*	*na*
Microcracking, cracking	Fatigue, thermal fatigue, thermal shock, creep, creep-fatigue	*PT*	1÷90%	20÷90%	1.5÷6.5 mm 6)
		MT	5÷90%	50÷90%	2.5÷10 mm 6)
Fracture, rupture	Overloading, brittle fracture	*VT*	*na*	*na*	*na*

1) MeT = metallography; MT = mechanical testing; DiM = dimensional measurement;
2) crack length; 3) crack depth; 4) welds min ca. 20%; 5) even > 5mm for welds; 6) typical range

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2.8. B. McGrath: PANI Experiment: Results and follow-up

- *Presentation*

serco

Serco Assurance

Presentation to

EPERC WORKSHOP

PANI Review

Bernard McGrath

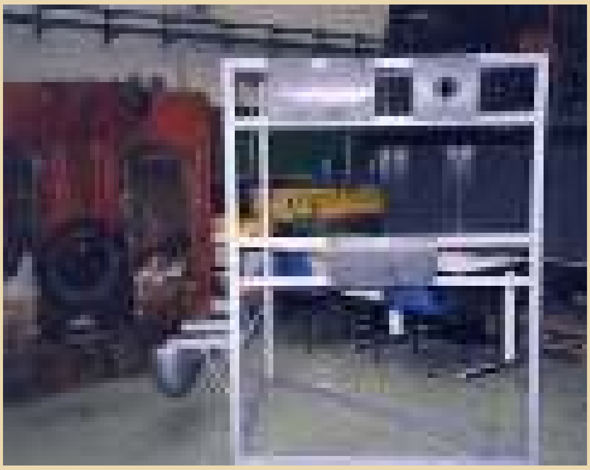
OBJECTIVE

To Investigate the Effectiveness of In-service Ultrasonic Inspection of Non-nuclear Plant

der Schnappschuβ

(Snapshot)

Environment



Results

- All Defects Sectioned
- Good Performance on Simple Geometry
- 'Poor Performance' overall reflects on technique and implementation as well as operator
- Variability in 'Similar' Operators
- Challenging Samples

Discussion

'Poor Detection'

- Low amplitude response
- Hidden in geometric echoes
- Short defect lengths compared to probe size
  - access difficulties
- Human factors
- Techniques not optimised

Response to Pani

- Improve NDT
  - Companies - NDT process
  - British Institute NDT / PCN
- Communication - die Kommunikation
  - HSE - die Richtlinien f✓r das beste Anwendungsverfahren
  - UT Published - www.hse.gov.uk/dst/ndt.pdf.
  - MPI / Dye Penetrant Final draft
  - Standards - interpretieren
- Benefits of potential improvements
  - PANI 2 - Just starting

Vigilance - Research

- Expectation - End Effect- 1st 30 minutes
- Frequent signals improve detectability
- Rest improves accuracy and speed (fidget)
- Presence of Authority figure gives improvement
- Breakfast !!!
- Loss of sleep not a factor
- Introvert / Less active / Intelligence / Youth
- Style / Posture
- Increase in skin conductance & blood pressure bad.

SOLUTIONS FOR THE FUTURE

PRESENTED BY Serco Assurance

Session III
TTF5 – Remaining Life Assessment, Life Management

Terms of Reference of TTF5

TERMS OF REFERENCE OF TTF5

Integrity Assessment During Operation

At the Steering Committee of November 2000 in Milan, a change in the title of TTF5 was approved, from Service Integrity and Life Extension to the more specific title: “Integrity Assessment during Operation”. This new title was intended to sharpen the scope of activities of TTF5, also in view of some changes in other TTFs, in particular the TTF3 which, on the contrary, decided to enlarge its scope (originally “Harmonisation of Inspection Programming in Europe”).
The EPERC TTF5 covers the pressure equipment (in particular defined in the Pressure Equipment Directive) and concentrates on plant operation aspects including component integrity, residual life assessment, repair and effect of material damage in the component integrity and residual life. TTF5 includes representatives from the plant operators, the end-users of PE, safety authorities, service providers and PE manufacturers. TTF5 is concerned with prevention & control of degradation & damage of pressure equipment due to long-term operation at high temperature, primarily temper embrittlement and creep.
TTF5 inherently covers several disciplines like creep, fatigue, fracture, material damage and ageing, experimental test methods for service exposed material characterisations, detection & monitoring of damage and developing an understanding of mechanisms to assist with prediction of future behaviour in operating equipment, and where possible, harmonisation of approaches to testing & assessment.

Technical activities are mainly conducted within 5 actions:

1	Promotion of Small Punch (SP) minimally invasive test method: – Standardisation of SP methods (at high and at low temperature), – in kind project: “Intercomparison exercise of Small Punch creep tests (round robin)”.
2	Repair methods and repaired components integrity assessment.
3	Survey of European experience of component repair methods and cases: results of a questionnaire on this theme will be possibly merging into a survey on the same topic carried out under item 2 above.
4	Set up of a Thematic Network on European Fitness for Service Integrity Assessment Procedure.
5	Promotion of flaw assessment methodologies against fracture and fatigue based on a crack sensitivity index methodology, related to the gradient of the stress intensity factors in components.

3.1. V. Bicego
Integrity assessment during operation *(Overview of TTF5 activities)*

INTEGRITY ASSESSMENT DURING OPERATION OVERVIEW OF TTF5 ACTIVITIES

V. Bicego (Chairman of TTF5)
CESI

Abstract

A change in the title of TTF5 was approved by the Steering Committee of EPERC at the end of 2000, from Service Integrity and Life Extension to the more specific title: "Integrity Assessment during Operation". This was intended to sharpen the scope of activities of TTF5, both in view of newly formed TTFs and of some changes in other TTFs, enlarging their scopes.

The TTF5 covers the pressure equipment (in particular defined in the Pressure Equipment Directive) and concentrates on prevention & control of degradation & damage due to long-term operation at high temperature. It inherently covers several disciplines like creep, fatigue, fracture, material damage and ageing, experimental test methods for service exposed material characterisations, detection & monitoring of damage and developing an understanding of mechanisms to assist with prediction of future behaviour in operating equipment, and where possible, harmonisation of approaches to testing & assessment.

TTF5 includes representatives from the plant operators, the end-users of PE, safety authorities, service providers and PE manufacturers.

Technical activities are currently conducted within 5 actions:

- Promotion of Small Punch minimally invasive test method (at high and at low temperature), namely by an in kind project: "Intercomparison exercise of Small Punch creep tests (round robin)".
- Repair methods and repaired components integrity assessment
- Survey of European experience of component repair methods and cases: results of a questionnaire on this theme will be possibly merging into a survey on the same topic carried out under the item above.
- Set up of a Thematic Network on European Fitness for Service Integrity Assessment Procedure.
- Promotion of flaw assessment methodologies against fracture and fatigue based on a crack sensitivity index methodology, related to the gradient of the stress intensity factors in components.

Integrity Assessment during Operation

TTF5 PRESENTATION

by:
Valerio Bicego
chairman of EPERC TTF5

CESI, Via Reggio Emilia 39, 20090 Segrate Milan - I

EPERC
European Pressure Equipment Research Council

TTF3, TTF5 and TTF7 Workshop on:
In Service Inspection and Life Management of Pressure Equipment
Stuttgart D, Oct 5th 2001

The EPERC TTF5 covers the **pressure equipment** (in particular defined in the Pressure Equipment Directive) and will concentrate on

plant **operation** aspects including component **integrity**,

residual life assessment,

repair

and effect of **material damage** in the component integrity and residual life.

TTF5 includes representatives from the plant operators, the end-users of PE, safety authorities, service providers and PE manufacturers.

TTF5 inherently covers several disciplines like **creep**, **fatigue**, **fracture**, material **damage** and **ageing**, **inspection**, **monitoring** and **measurements** at **all temperatures**.

It is recognised that some of these technical areas are of interest to members of other TTFs. The operating agent shall endeavour to ensure open flow of information to the interested groups.

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TTF5 Integrity Assessment during Operation
Members list (begin 2001)

Company	Name	Company	Name
CETIM - CAD / CAE Department	Afzali	EC JRC – IAM	Hurst
Labein	Azpiazu	TÜV AW/TÜV Süddeutschland	Joas
Consultant for Pressure Equipment	Baylac	Royal & SunAlliance Engineering	Law
EDF - Electricite de France	Bethmont	MPA Stuttgart	Maile
CESI SpA, IT	Bicego (chairman)	Force Institute	Mortensen
Creusot Loire Industrie	Bocquet	ENEL Research Pisa	Piccitto
Institute de Soudure	Boucher	EC JRC – IAM	Rantala (co-chairma
Mitsui Babcock Energy Ltd	Buchanan	Instituto Italiano della Saldatura	Servetto
Ecole des Mines de Douai	Caenen	ETD-European Techn. Development	Shibli
The Welding Institute	Cane	SAQ Kontroll AB	Storesund
University of Bologna	Cesari	Tecnatom-Special Prod. Division	(Tauroni)
Belgian Welding Institute	Coussement	EC JRC – IAM	Taylor
Strutech Consultancy	Darlaston	KEMA	van Vulpen
Centro Sviluppo Materiali	Di Gianfrancesco	Hellenic Foundries	Vassilas
AIB-Vincotte Pressure Equipment	Dorlodot	Esso Petroleum Ltd	Winnik
TÜV Nord Gruppe Anlagentechnik	Freisenhausen	TNO Inst. of Industrial Technology	van Wortel
Allianz Zentrum für Technik GmbH	Hagn	TU Vienna INS	Zeman
EMPA	Harzenmoser		

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TTF5 Integrity Assessment during Operation
(up to end of 2000 title was: Service Integrity and Life Extension).

TTF 3	TTF 5
Risk Informed Assessment – Monitoring and Maintenance	A common interest
Inspection Capability Evaluation	
Qualification of Inspection Procedures and Equipment	
Quality programs to Maintain the Effectiveness of the Qualified Inspection	
Information Based schemes for Optimum Inspection and Monitoring	
New Methods for Cost-effective and Reliable Inspections of PE	
	Plant operation issues
Common interest: NDE is an integral part of Int. A.	Integrity Assessment (FITNET!)
	Life extension
	Repair welding
	Material degradation
	Creep damage
	Material characterisation (mechanical properties)
	(Maintenance)

TTF5: Integrity Assessment During Operation

Technical activities:

1 **Promotion of Small Punch minimally invasive test method:**
- **Standardisation of Small Punch methods (at high and at low temperature),**
- **in kind project: "Intercomparison exercise of SP creep tests (round robin)".**

2 **Repair methods and repaired components integrity assessment.**

3 **Survey of European experience of component repair methods and cases (parallel to INTEGRITY project)**

4 **Set up of a Thematic Network on European Fitness for Service Integrity Assessment Procedure.**

5 **Promotion of flaw assessment methodologies against fracture and fatigue based on a crack sensitivity index**

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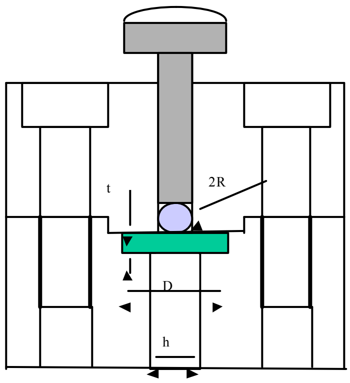
Small Punch testing method

For measuring materials mechanical properties:

- **Directly**

- **Small volume of specimen (local areas of damage, small regions e.g. HAZ and coatings, minimally invasive sampling from service components)**



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SP interest in Europe

CESI (ENEL Group), IT	Belgian Ist. Of Welding, BE
Ist. de Sold. e Qualidade, PT	Electr. D. Portugal PROET, PT
Petrogal, PT	GKSS, D
JRC Petten, EC-DG12	Mitsui Babcock, UK
Un. Wales Swansea, UK	ERA, UK
VITKOVICE, CZ	MPA Stuttgart, D
TNO, NL	POWERGEN, UK
Laborelec, BE	Aerospatiale-Matra, FR
National Power, UK	BASF, D
ELSAMPROJEKT, DK	Centro Ricerche Fiat, I
Labein, SP	TUV Nord, D
AZT, D	DNV (ex SAQ), NOR
MT Integridade, PT	KTH (NOR)
KEMA, NL	Force, NOR
Electr. de France, FR	IPM, CZ
TWI (UK)	IMT Lubjana SL

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Small Punch project proposal to M&T:

MINIMALLY INVASIVE TESTING METHOD FOR MECHANICAL PROPERTIES MEASUREMENT (MITE)

Measurement & Testing

The MITE proposal intends to fully develop a strongly miniaturised mechanical test technique, the so called Small Punch method, for the measurement of mechanical properties of materials utilising small specimens which may be sampled from plant components during shut downs for maintenance, or can be utilised in all conditions when material characteristics in a local zone or size restrictions for the samples exist.

CESI, CRF, ERA, EDF, UWS, ISQ, PETR, KTH, DNV, JRC, VITK, MPA, KEMA

Presented on March 2001 (Ded. Call)

FAILED

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SMALL PUNCH CREEP Contribution in Kind PROJECT

CESI, ERA, JRC, CRACOW, KEMA, UWS

Objective: to compare existing test practice (methodology, reproducibility)

Fields of possible consideration:

HIGH TEMPERATURE (CREEP):	**YES**
TENSILE PROP., FATT/NDTT, FRACTURE TOUGHNESS	**NO**

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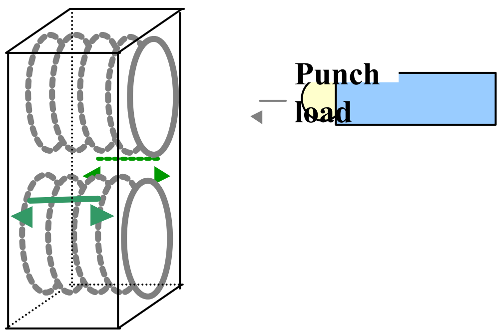
Material: 1CrMoV, procured by National Power / Swansea Un.



CESI produced the test criteria & general conditions
ERA (CESI) is coordinating test progress (temperatures)
UWS provides material and 1-D data
JRC will collect and assess the creep rupture data (final report)
KEMA will produce a special report

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SMALL PUNCH CREEP Contribution in Kind PROJECT
Status: started since April 2000, SP creep tests ongoing

Results (in italics: 20 Sep 2001):

			Time to rupture	notes
CESI	625 °C	300 N	152 hr but underloaded	128.6 hr, using n=6.5 (Swansea)
CESI	625 °C	300 N	145.61 hr	
CESI	625 °C	300 N	218.72	
ERA	625 °C	300 N		Just starting
ERA	625 °C	300 N		
ERA	625 °C	300 N		
JRC	625 °C	300 N	78.59 hr	Deflection at fracture: 1.40 mm
JRC	625 °C	300 N	77.45 hr	Deflection at fracture: 1.39 mm
JRC	625 °C	300 N	97.92 hr	Deflection at fracture: 1.20 mm
JRC	625 °C	300 N	173 hr	Extrapoled by M.-G. Relationship (m=1)
JRC	625 °C	300 N	170 hr	Extrapoled by M.-G. Relationship (m=1)
VITK	625 °C	300 N		Unable to work
VITK	625 °C	300 N		
VITK	625 °C	300 N		
UWS	625 °C	300 N		*106*
UWS	625 °C	300 N		
UWS	625 °C	300 N		
KRAK	625 °C	300 N		Wrong conditions, and in air!
KRAK	625 °C	300 N		
KRAK	625 °C	300 N		

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Project proposal from Prof. L. Toth, Bay Zoltan Institute, Hungary.

Crack propagation sensitivity of the pressurised equipment's

Goal : To develop a tool which is able to join the level of reliability assessment of the pressurised equipment and the NDT testing results

- **Definition of the crack propagation sensitivity index concept of pressurised equipment working at quasistatic and cyclic loading conditions**
- **Development general tool for estimating the effect of residual stress on the crack propagation sensitivity index of pressurised equipment**
- **Development general tool for creation of NDT guidelines of diffe rent kind of pressurised equipment having crack like defects**
- **Ttypical pressurised equipment: pipelines, pressure vessels, val ves, T-joins, etc.**

Partners: Bay Zoltan, IIS, CEODECO, ISQ, MTINT, ISAM (EL), MPA, IWM, GKSS, TNO, SGS NL, METZ Un., Wars. Un.

Status: Retained, under Negotiation (?)

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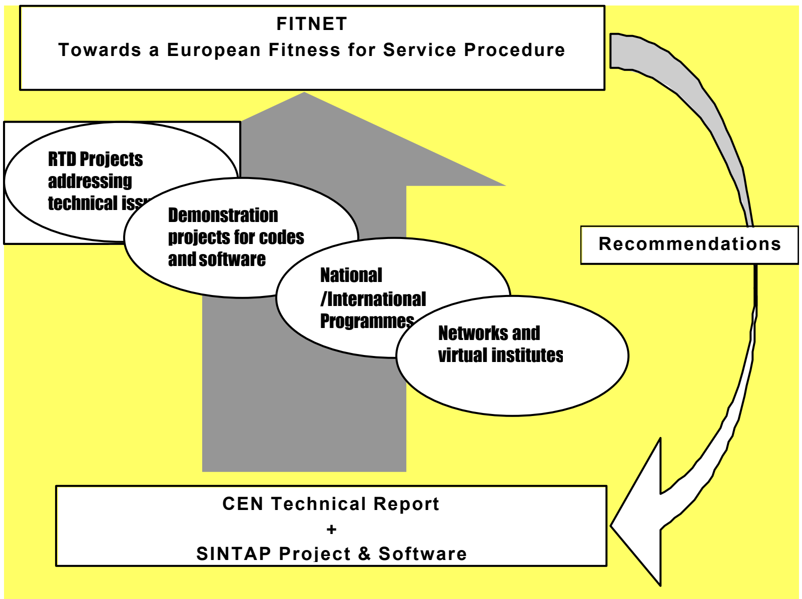

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European Fitness for Service Network
(FITNET)

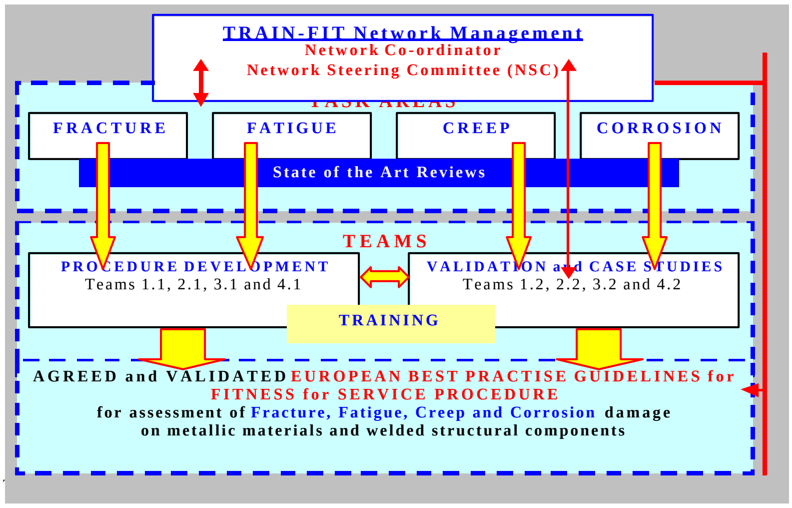
Abstract

FITNET will promote the development of a European Fitness-for-Purpose Procedure for assessing the structural integrity of metallic structures transmitting loads. In particular it will cover techniques for dealing with known or postulated defects and will consider the failure modes of fatigue, fracture, creep and environmental assisted cracking. The network will harness recent technological advances from EC-funded projects, national programmes and in-kind contributions. Working groups will be established to review existing standards, to create a database of validation tests and to produce consensus recommendations for a European structural integrity assessment procedure.

Contractors: GKSS, JRC, VTT, TWI, UNICAM, CESI, CORUS, CAT, BE, SHELL
Members: CSM, CRF, IIS, ALSTOM UK, DNV, MPA, FORCE, and others.

Status: Retained, under negotiation

Training for Fitness–for–Service Evaluation and Optimum Design of Metallic Materials „TRAIN-FIT“



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Conclusions

Recently promoted & ongoing major activities:

SP CoP proposal to M&T	failed
SP in kind creep round robin	ongoing
INTEGRITY project for GROWTH	ongoing
CRACKSENS proposal, GROWTH	in negotiation
FITNET, TN for GROWTH	in negotiation
TRAINFIT proposal, TN for Hum. Cap. Mob.	pending

Presently under consideration (a new possible Proposal):
Data Base of Materials Reference Curves

3.2. M. Afzali, M. Dubois
Applications of Integrity Assessment: Methods and Procedures

- *Presentation*

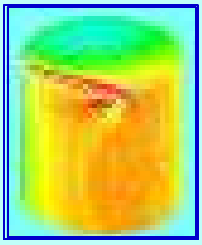
Applications of Integrity Assessment : Methods and Procedures

M. AFZALI - M. DUBOIS
CETIM Senlis

Applications of Integrity Assessment : Methods and Procedures

1 - ~~Introduction~~

- **To protect the human lives**
- **To protect the environment**
- **To ensure the security of the installations**
- **To prevent and to control the damages**
- **To control the maintenance cost**



Methodology of Risk Analysis

2 - Methodology of Risk Analysis

- **Design or Maintenance**

  a) ***Static loading***

  - Brittle fracture
  - Ductile deformation
  - Large creep deformation
  - Rupture under corrosion
  - Large deformation
  - Elastic or elasto-plastic instability

  b) ***Dynamic loading***

  - Rupture under crack propagation
  - Large deformation

Methodology of Risk Analysis

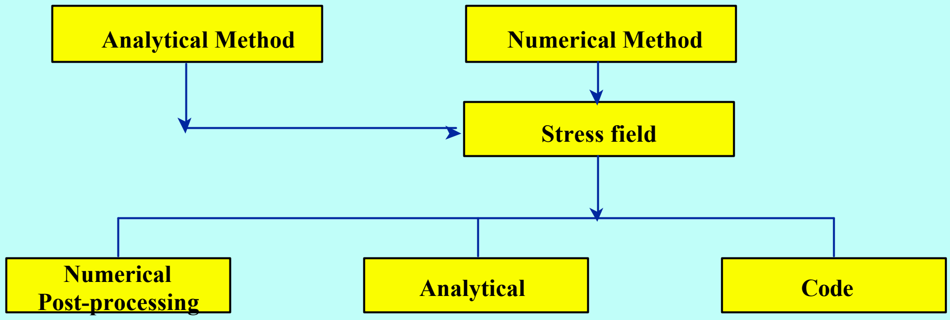
2 -1 *Damage source identification*

- **Identify failure modes**
- **First approximation - linear analysis**
- **Non-linear analysis**
  - **Large deformation**
  - **Creep**
  - **Elasto-plastic instability**
  - **...**

Fracture Mechanics

3 - Fracture Mechanics

Crack assessment



Fracture Mechanics

3 -1 *~~Parameters definitions~~*

a) Stress Intensity Factor

$$K_I = \lim_{r \to 0} \sqrt{\frac{2\pi}{r}} \frac{E}{E'} U_y (r, \theta = \pi) \qquad (1)$$

$E' = 4(1-\nu^2)$ **for plane deformation**

$E' = 4$ **for plane stress**

$U_y =$ **displacement at y direction**

or from stress :

$$K_I = \lim_{r \to 0} \sqrt{2\pi r}\, \sigma_y (r, \theta = 0) \qquad (2)$$

$$K_I = \alpha \sigma_o \sqrt{\pi a}$$

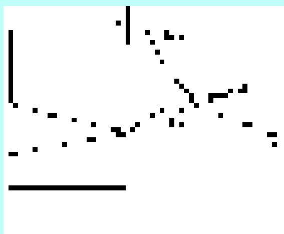


Figure 1

Fracture Mechanics

3 -1 *Parameters definitions (Cont'.)*

b) Rice-J Integral

The rice integral equation [5] based on energy balance is expressed as :

$$J = \int_c \left(w\, d\, x_2 - t_i \frac{\partial u_i}{\partial x_i}\, dc \right) \qquad i = 1,\ 2,\ 3$$

$$t_i = \sigma_{ij}\, n_j$$

$$J = J_e + \int_{s_p} \sigma_{ij} \frac{\partial \varepsilon^p_{ij}}{\partial x_i}\, dS$$

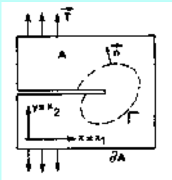


Figure 2 : *J* integral contour

c) Limit criteria

$$K_I \le K_{IC}$$

$$J \le J_C$$

Fracture Mechanics

3 -1 *~~Parameters definitions~~ (Cont'.)*

d) Relationship between the parameters

$$J = \frac{1}{E}\left(K_I^2 + K_{II}^2\right) + \frac{1+\nu}{E} K_{III}^2 \qquad \text{plane stress}$$

$$J = \frac{1-\nu^2}{E}\left(K_I^2 + K_{II}^2\right) + \frac{1+\nu}{E} K_{III}^2 \qquad \text{plane deformation}$$

e) Fatigue

Paris law crack propagation

$$\frac{da}{dN} = C\,(\Delta K)^m$$

crack propagation / cycle

Fracture Mechanics

3 -2 *Numerical Methods*

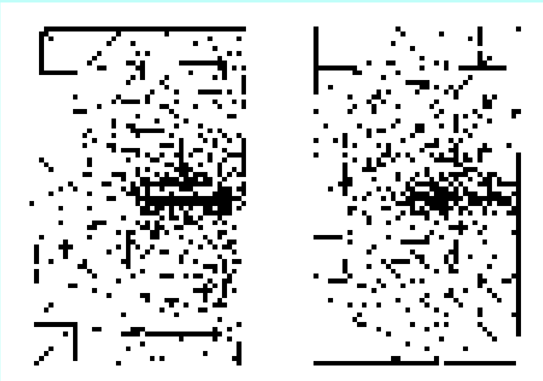
- **Finite Elements**
- **Boundary Elements**
- **Fracture Mechanics Post-processing**

  - **Influence of Mesh Refinement**

b = 50 mm
h = 40 mm
e = 10 mm
a = 25 mm

Fracture Mechanics

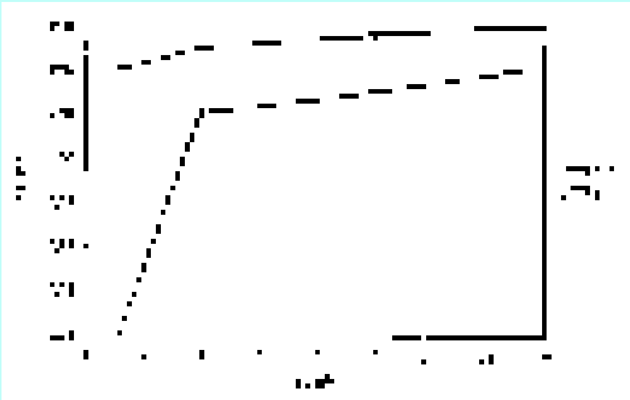
3 -2 *Numerical Methods*



Different mesh Refinements

Fracture Mechanics

3 -2 *Numerical Methods*



Influence of Mesh Refinement

Methods and Procedures for Risk Evaluation

4 - Methods and Procedures for Risk Evaluation

4 -1 *French RCC-M*

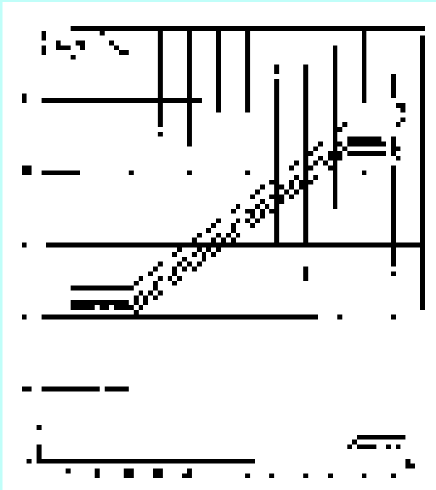
Thickness	Crack depth	Crack length
< 100 mm	25 mm	150 mm
100 à 300 mm	1/4 Thickness	1/5 Thickness
> 300 mm	75 mm	450 mm

$$K_I = \alpha \left(M_m \sigma_m^p + M_b \sigma_b^p \right) + M_m \sigma_m^s + M_b \sigma_b^s$$

$$M_b = \frac{2}{3} M_m$$

Methods and Procedures for Risk Evaluation

4 -1 *French RCC-M (Cont'.)*



Methods and Procedures for Risk Evaluation

4 -1 *~~French RCC-M~~ (Cont'.)*

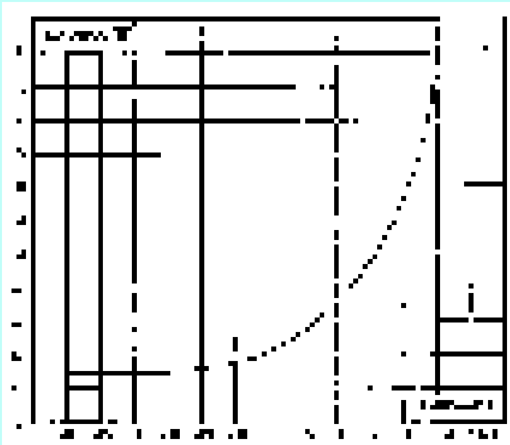
Polynomial Function

$$\sigma(X) = \sigma_0 + \sigma_1\left(\frac{X}{t}\right) + \sigma_2\left(\frac{X}{t}\right)^2 + \sigma_3\left(\frac{X}{t}\right)^3 + \sigma_4\left(\frac{X}{t}\right)^4$$

$$K_I = \sqrt{\pi a}\left(\sigma_0\, i_0 + \sigma_1\left(\frac{a}{t}\right) i_1 + \sigma_2\left(\frac{a}{t}\right)^2 i_2 + \sigma_3\left(\frac{a}{t}\right)^3 i_3 + \sigma_4\left(\frac{a}{t}\right)^4 i_4\right)$$

Methods and Procedures for Risk Evaluation

4 -1 *French RCC-M (Cont'.)*



Methods and Procedures for Risk Evaluation

4 -2 *R6 or 2 Criteria Rule*

$$K_r = \frac{K_I(a,\sigma)}{K_{IC}} \quad , \quad S_r = \frac{\sigma}{\sigma_0}$$

$$\sigma_0 = \sigma_y \quad \text{ou} \quad \sigma_f$$

$$\sigma_f = \frac{\sigma_u + \sigma_y}{2}$$

σ_u : **Ultimate Stress**

σ_f : **Stress d'écoulement**

Methods and Procedures for Risk Evaluation

4 -2 *R6 or 2 Criteria Rule*

Crack Model	Plane Deformation		Plane Stress	
Behaviour	Elastic	Elasto-plastic		
		Initiation		Ductile Rupture & instability
Crack Criteria	K_{IC} J_{IC} δ_{IC}	J_{IC} δ_{IC}	J_R Curve R	Curve R

Software for Risk Evaluation

5 - Software for Risk Evaluation

5 -1 *Software for Stress Analysis*

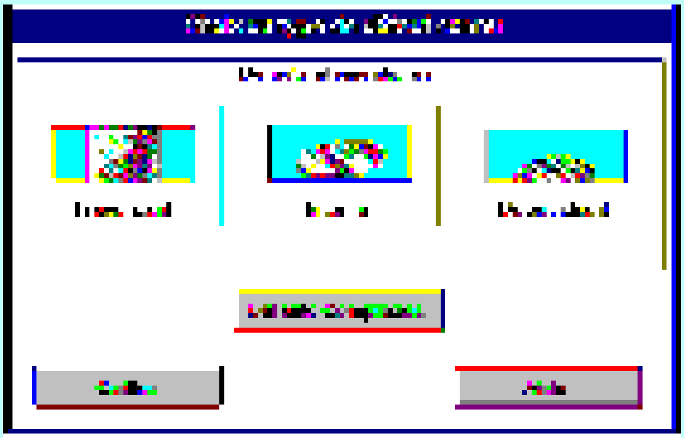
- **Finite Elements**
- **Boundary Elements**
- **Analytical solutions**

5 -2 *Software for Risk Analysis*

- **Analytical solutions**
- **Based on standard procedures**

Software for Risk Evaluation

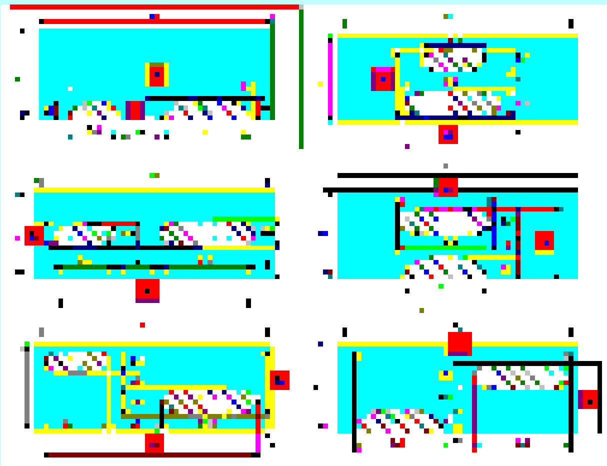
CETIM-Secure : Software for Risk Analysis on Windows



Software for Risk Evaluation

CETIM-Secure : (Cont'.)

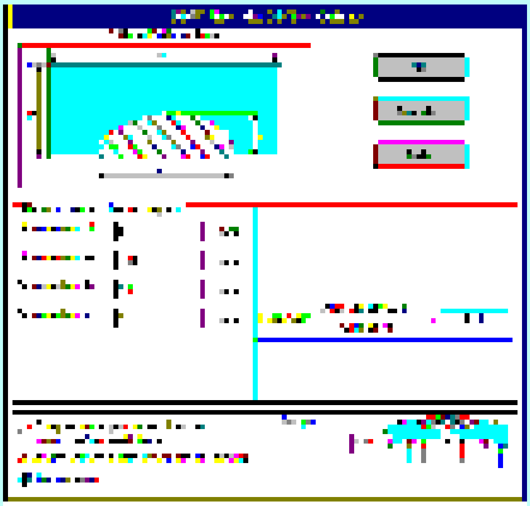
Crack Interaction



Software for Risk Evaluation

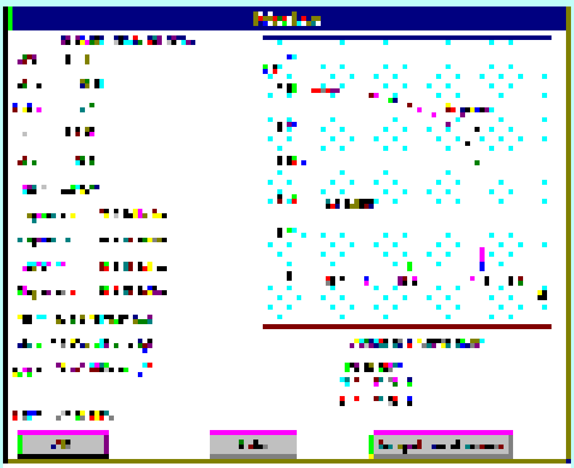
CETIM-Secure : (Cont'.)

- ✓ **Crack Definition**
- ✓ **Material Data Base**
- ✓ **Loading**



Software for Risk Evaluation

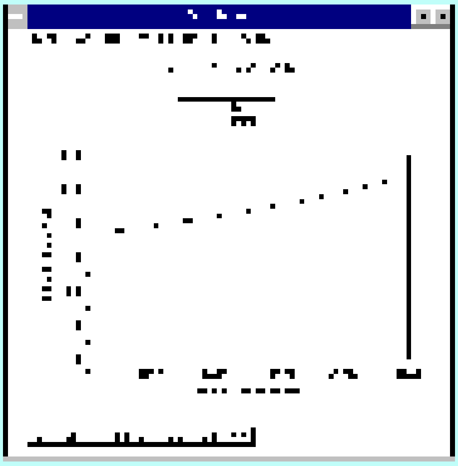
CETIM-Secure : (Cont'.)



Software for Risk Evaluation

CETIM-Secure : (Cont'.)

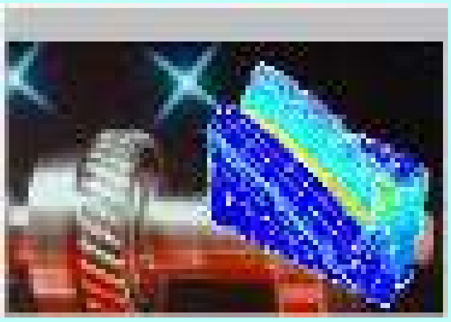
Fatigue Analysis



Industrial Applications

6 - Industrial Applications

- **Finite Elements**
- **Boundary Elements**
- **Analytical solutions**



7 - Conclusions

- **Design process**

  - Modelling the structure behaviour
  - Stress analysis
  - Fatigue analysis
  - Fracture Mechanics Analysis based on "Theoretical Crack Shape"

- **Maintenance**

  - Identify the failure modes
  - Stress linear/non-linear analysis depending on the environment incident
  - Risk analysis taking into the damage nature

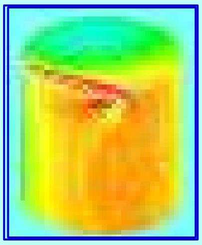
7 - Conclusions (Cont'.)

- **Standard Methodology Risk Analysis**

  - Agreed procedures at international level
  - Cost Reduction

- **Software**

  - Insure Quality Assurance
  - Efficiency



3.3. M Kurzydlowski, W. L. Spychalski and A. Zagórski
Failure of a high pressure polyethylene reactor - analysis and safety measures

- *Presentation*

Failure of High Pressure Polyethylene Reactor:
Analysis and Safety Measures

Krzysztof J.Kurzydłowski, Wojciech L. Spychalski and Andrzej Zagórski

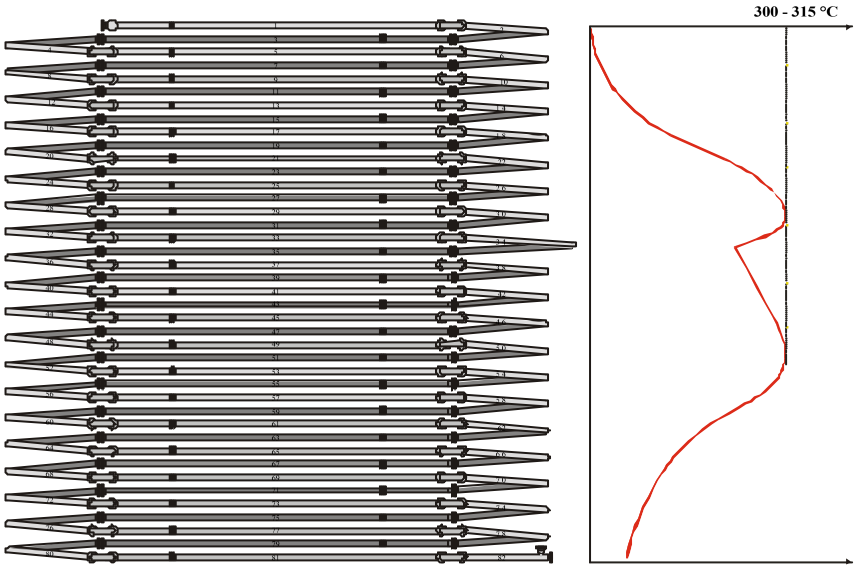
Warsaw University of Technology
Materials Science and Engineering Faculty

Polyethylene installation

- Internal Pressure > 150 Mpa
- Temperature ≈ 150°C
- Cyclic changes of the pressure (different amplitudes and frequencies)
- Decomposition of polyethylene

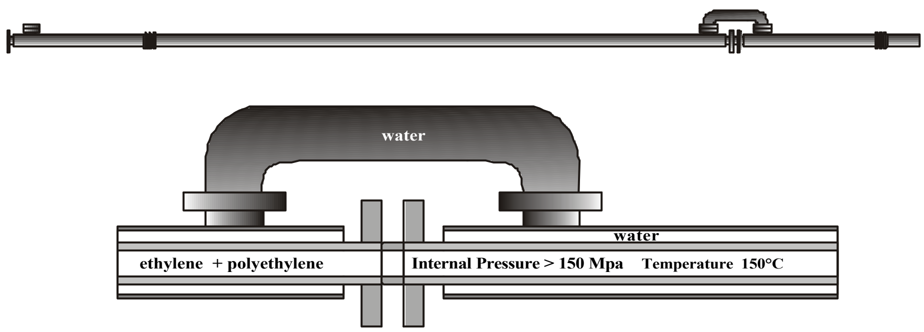
Polyethylene installation

- Pipe-type reactor



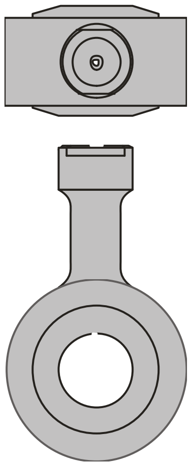
Polyethylene installation

- Pipes with cooling jackets
- Joints, some with thermocouple outlet



Polyethylene installation

• Joints, some with thermocouple outlet



The failure

• Sudden leak of the mixture of substrates and the polyethylene
• Explosion
• Mechanical shock and fire

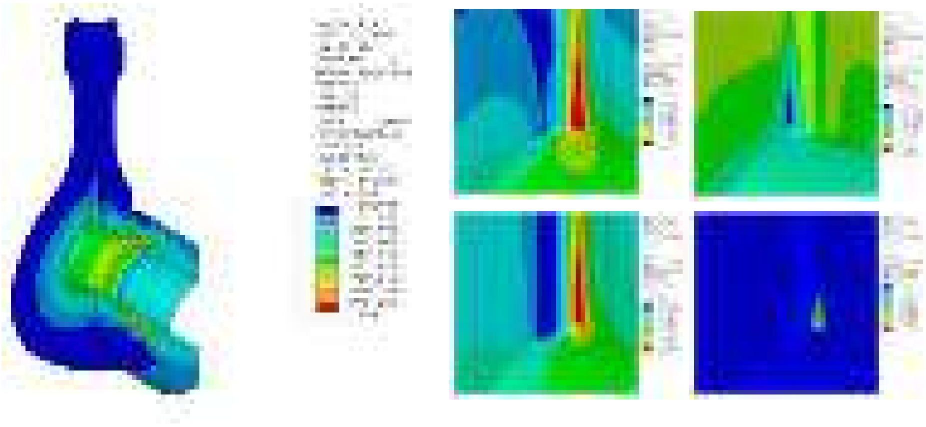
The failure

Investigations

- Identification of the leaking element
- Modeling of the leakage

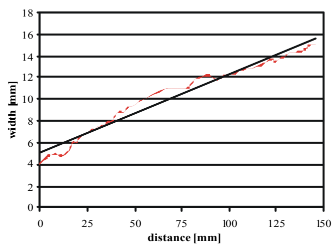
Investigations

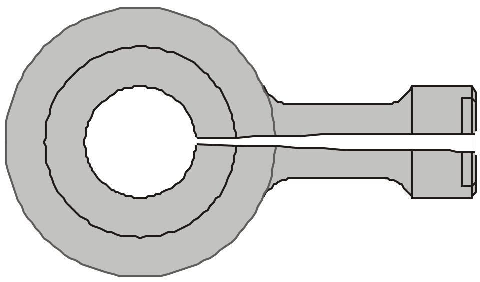
• Examinations of the thermocouple joint



Examinations of the joint

• Macroscopic observations





Examinations of the joint

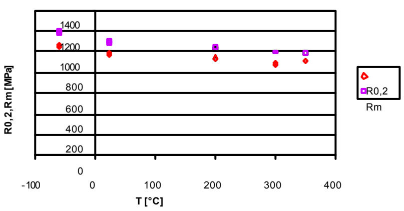
- Chemical composition

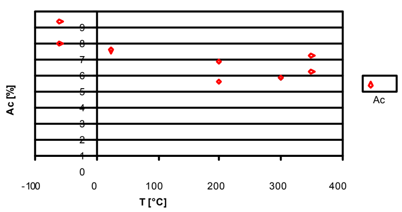
C	0,08-0,21
Si	**0,14-0,38**
Mn	0,36-0,54
Cr	1,39-1,92
Ni	3,62-4,16
Mo	0,37-0,48
S	0,009-0,093
P	<0,027
Fe	balance

Examinations of the joint

- Mechanical properties

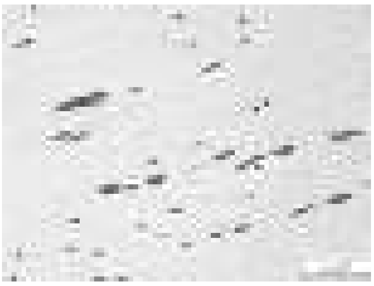
T [°C]	**$R_{0,2}$(*) [MPa]**	**R_m (*) [MPa]**	**A_c (*) [%]**
- 60	1050	1176	7,0
- 60	1060	1196	8,4
23	980	1102	6,7
23	970	1085	6,6
200	930	1025	4,7
200	940	1040	5,9
300	880	999	4,9
300	890	993	4,9
350	915	990	6,3
350	910	981	5,3





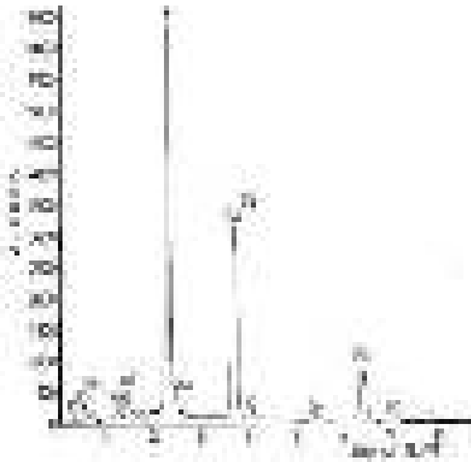
Examinations of the joint

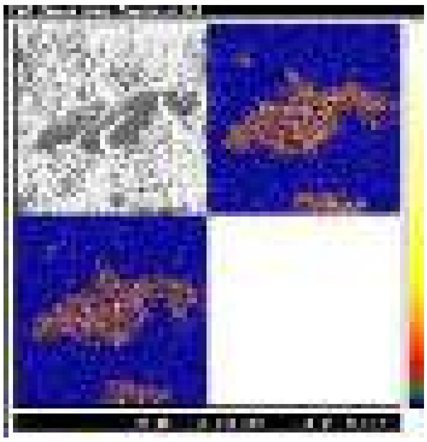
- Microstructure



Examinations of the joint

- Microstructure



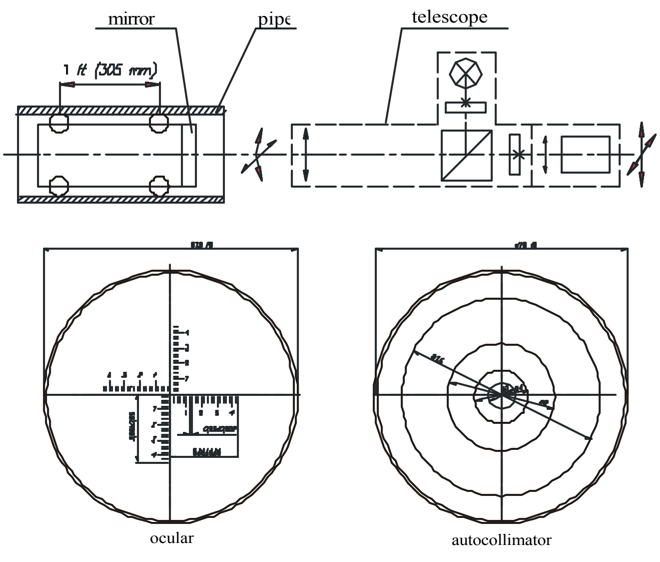


Preventing measures

- In-service inspection program
- Auto-fretage of the joints and pipes
- Pressure-diameter hysteresis
- Acoustic emission

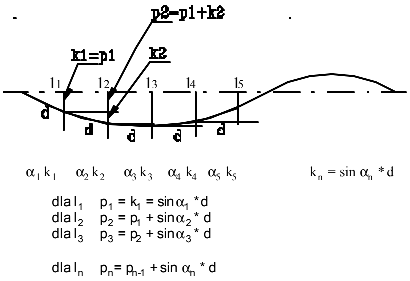
In-service inspection

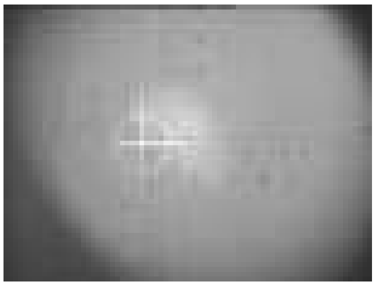
- Linearity checks (alignment of pipes)

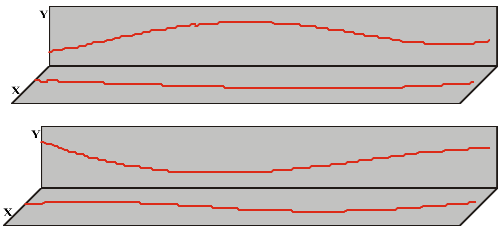


In-service inspection

- Linearity checks (alignment of pipes)

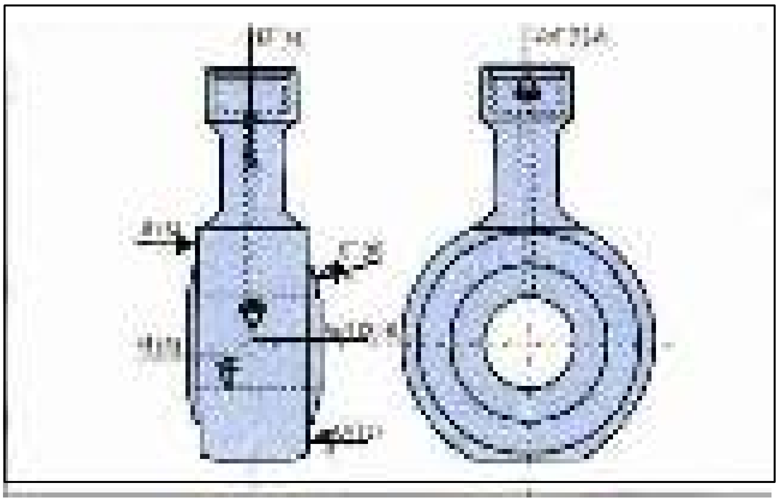






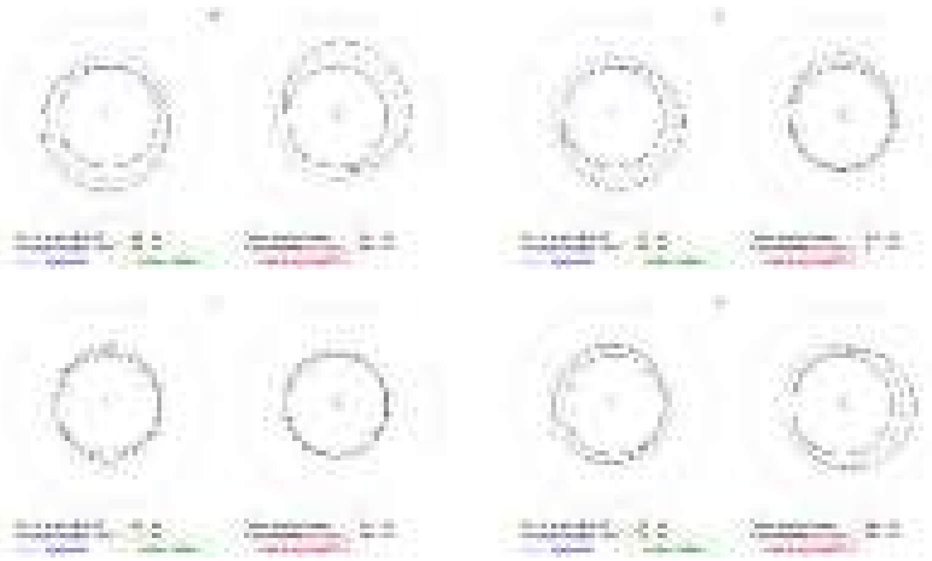
In-service inspection

- Visual examinations (surface defects)
- Eddy current (cracks)
- Ultrasonic (cracks and attenuation)



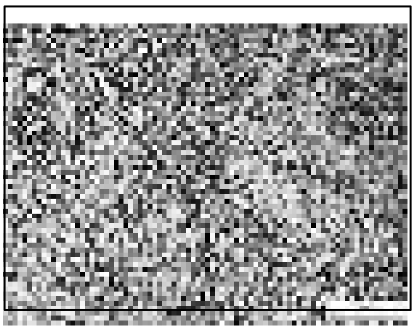
In-service inspection

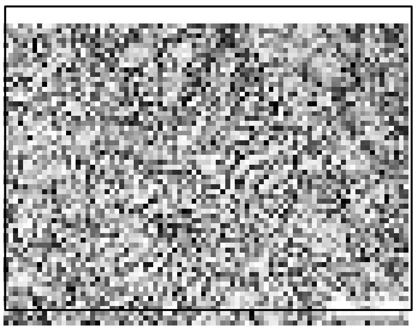
- Hardness (average and variation)



In-service inspection

- In-situ microscopy (digital replicas)
- Acoustic emission





3.4. O. Klementis, L. Toth, G. B. Lenkey: Case study database for chemical plants

- *Presentation*

(Failure)Case Study Database for Chemical Plants

O. Klementis, L.Tóth, G.B.Lenkey

EPERC Workshop on

In-Service Inspection and Life Management of Pressure Equipment

Stuttgart, Germany, October 5, 2001

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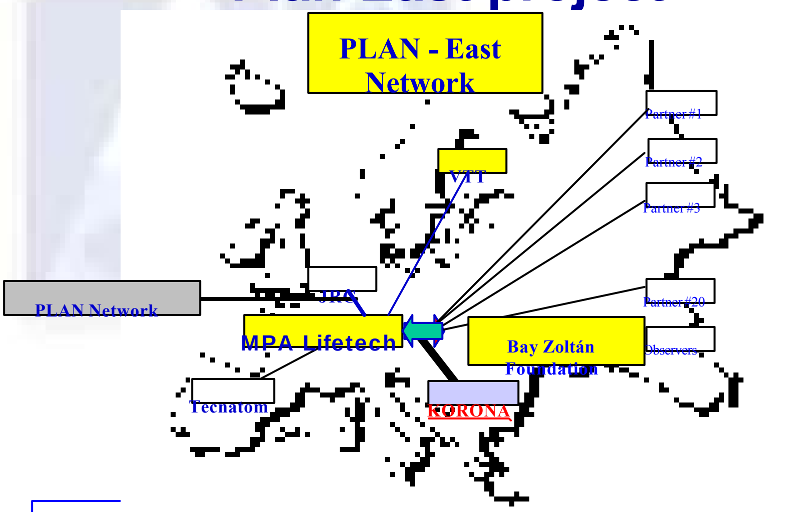
Plan East project



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OBJECTIVES of the PLAN_EAST project

- creating information booths in *all of the participating countries* which dissemi-nates the PPT related information within their own countries,
- creating "Home Pages" containing all the available information related PPT
- strengthening the modern information technology in CEEC/NIS countries

Bay Zoltán Foundation for Applied Research

Clusters

- Cluster 1 – Inspection,
- Cluster 2 - Instrumentation/ Monitoring,
- Cluster 3 - Structural Mechanics,
- Cluster 4 – Maintenance

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Structural Mechanics Cluster

LEADER

Bay Zoltán Instute for Logistics and Production Systems

TASKS

- **Info Database**
- **Material Database**
- **Case Study Database**

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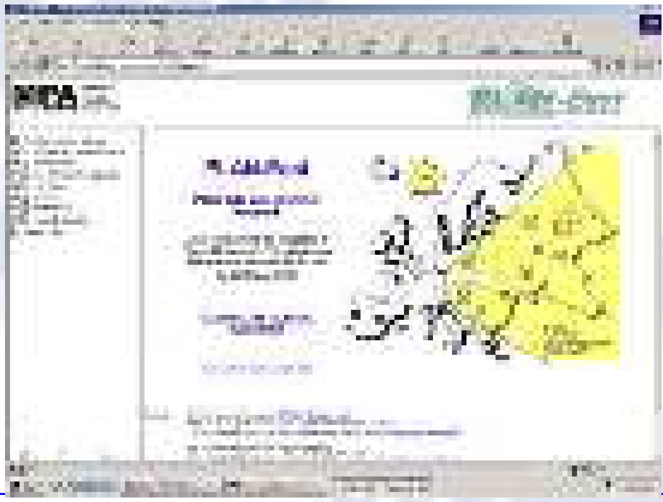
RESULTS

www.planaisht.uni-stuttgart.de/Planeast/



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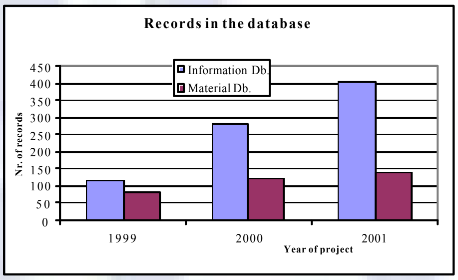
InfoDatabase

www.planaisht.uni-stuttgart.de/Planeast/



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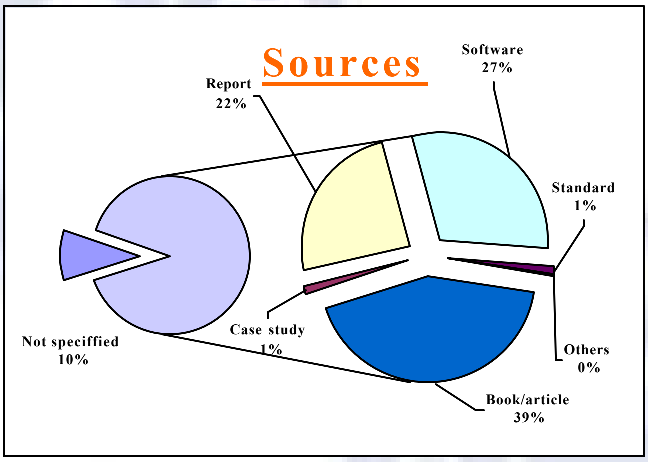

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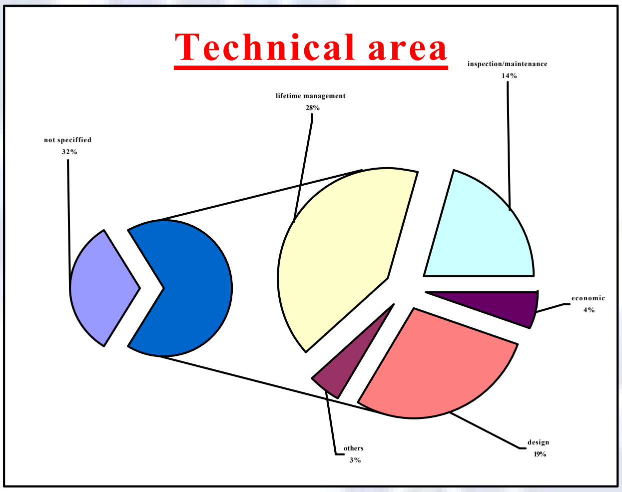

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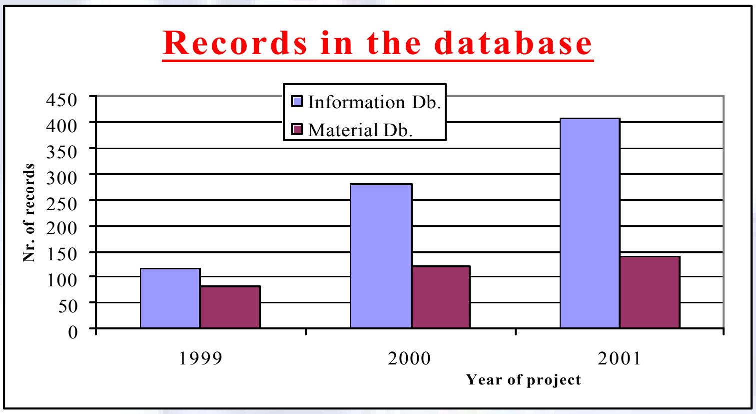
MaterialDatabase



www.planaisht.uni-stuttgart.de/Planeast/

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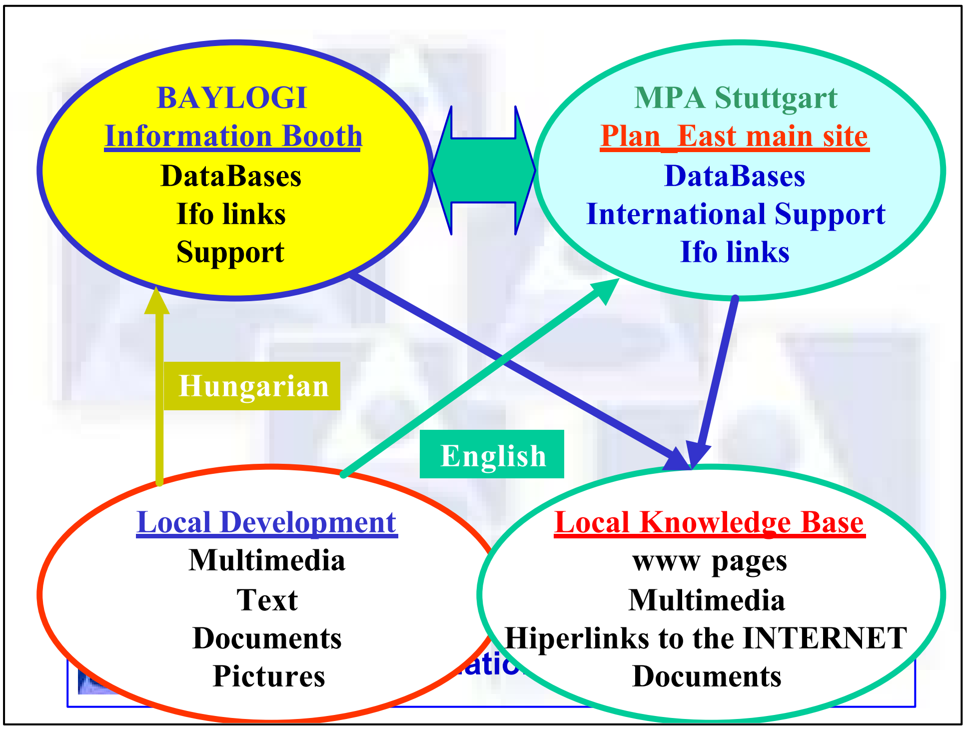
BAYLOGI
Information Booth
DataBases
Ifo links
Support
MPA Stuttgart
Plan_East main site
DataBases
International Support
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English
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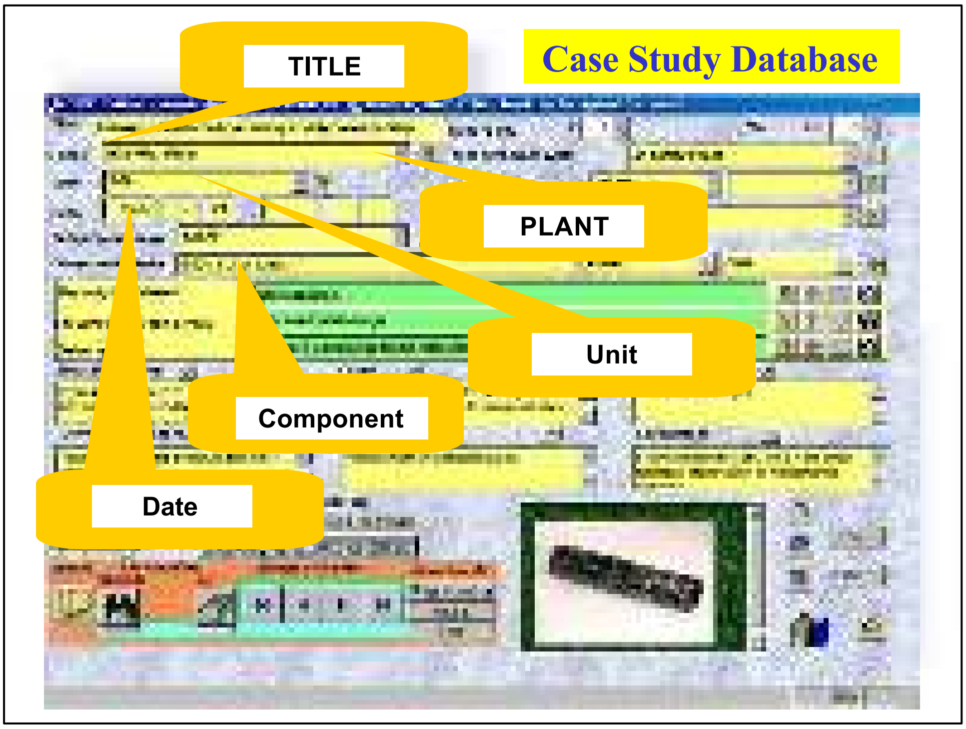
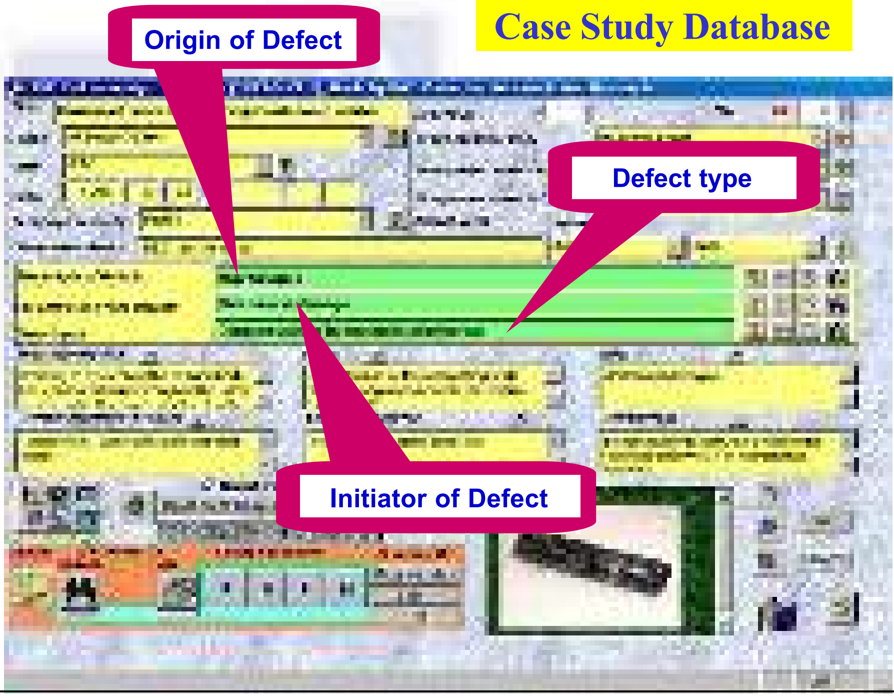
Documents


TITLE
Case Study Database
PLANT
Unit
Component
Date

Case Study Database



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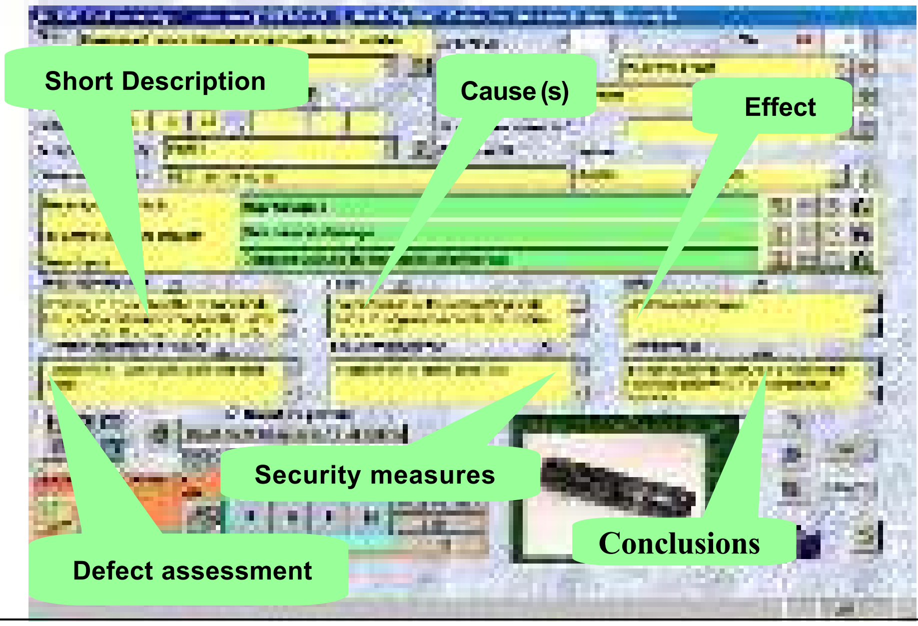
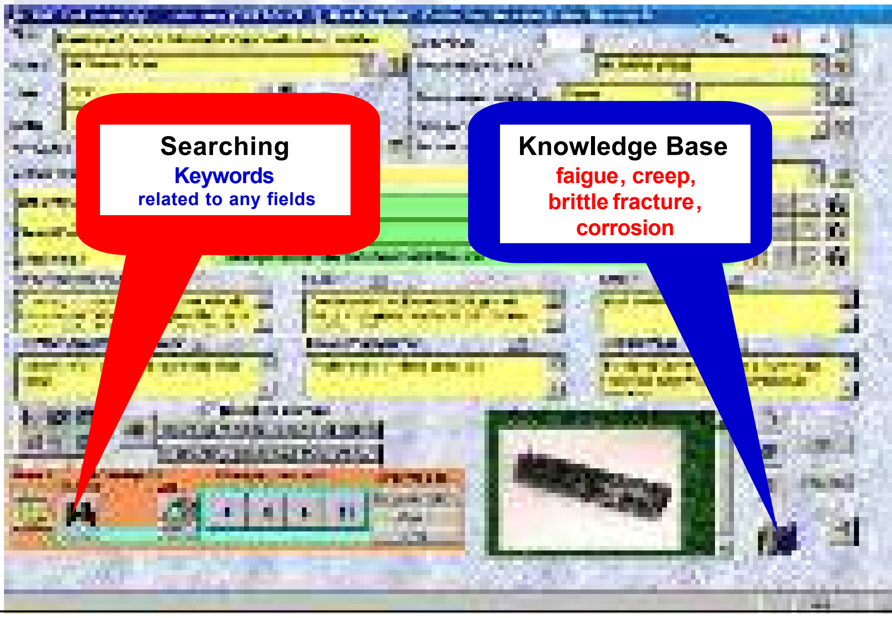
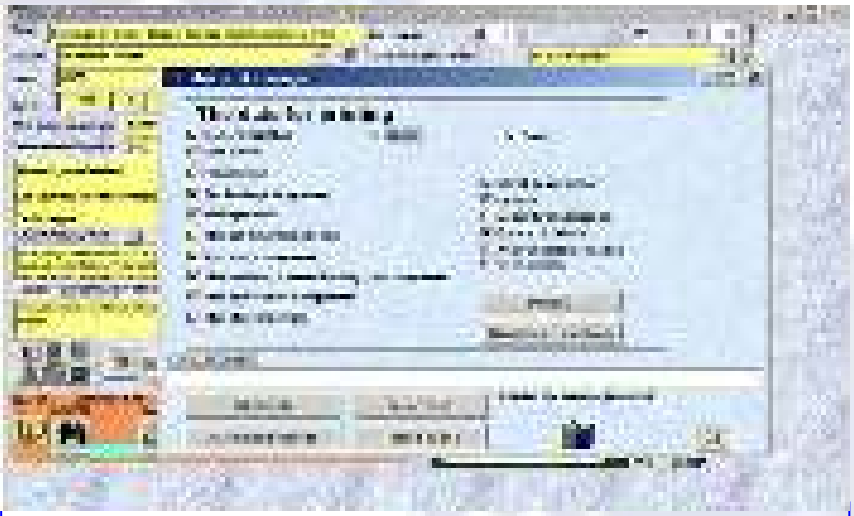


Case Study Database



Case Study Database



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Case Study Database

Content of the DataBase

⇒ 400 records for case studies

⇒ 20 records for knowledge base (fatigue, corrosion, brittle fracture, etc.)

⇒ 200 references (books, papers, Internet links, etc.)

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Session IV
TTF7 – Field inspection for Hydrogen Damage detection

Terms of Reference of TTF7

4.1. *R. Koers, P. Castello:* Hydrogen Damage *(Overview of TTF7 Activities)*

4.2. *G. Dobmann, S. Hirsekorn and U. Netzelmann:* Limits of Ultrasonic Backscattering and Phase Velocity Measurement for the Non-destructive Characterization of Hydrogen Attack – Numerical Simulation for Technical Justification

4.3. *F. Bresciani, F. Peri:* Non intrusive inspection methods and assessment criteria adopted for SSC, HIC and SOHIC detection: experience of IIS

4.4. *F.-W. Bach, K.L. Feiste,, W. Reimche and W. Weber:* Perspectives for the determination of hydrogen induced material degradation with electromagnetic inspection techniques

TERMS OF REFERENCE OF TTF7

Hydrogen Damage

The overall objective of TTF7 is that of solving problems related to hydrogen damage in materials in a co-ordinate manner, for the benefit of the European Industry and for a higher safety and cost-effective management of related components and infrastructures. TTF7 is concerned with prevention & control of degradation & damage of pressure equipment due to hydrogen effects. This covers high & low temperature service, detection & monitoring of damage and developing an understanding of mechanisms to assist with prediction of future behaviour in existing & new equipment, and where possible, harmonisation of approaches to testing & assessment.

Scheme of technical activities	
High Temperature - Equipment	**Low Temperature - Sour services**
Hydrogen Embrittlement	Wet H_2S
Minimum Pressurisation Temperature (MPT)	Environment
High Temperature Hydrogen Attack (HTHA)	Hydrogen Induced Cracking, Stress Oriented Hydrogen Induced Cracking (HIC-SOHIC)
Assessment, inspection and monitoring	Assessment, inspection and monitoring
Welding and repair	Welding and repair
New materials	New materials

4.1. R. Koers, P. Castello
Hydrogen Damage (Overview of TTF7 Activities)

- *Abstract*
- *Presentation*

HYDROGEN DAMAGE – OVERVIEW OF TTF7 ACTIVITIES

R. Koers (Chairman of TTF7)
SHELL Global Solutions

P. Castello (Co-Chairman of TTF7)
European Commission-DG JRC-Institute for Energy

Abstract

Since its official launch on October 26-27, 2000, the EPERC Technical Task Force 7 (Hydrogen Damage) has evolved into a group counting 107 affiliates representing some 85 organisations from 13 European Countries. These include industries, research laboratories and inspection bodies. The overall objective of TTF7 is that of solving problems related to hydrogen damage in materials in a co-ordinate manner, for the benefit of the European Industry and for a higher safety and cost-effective management of related components and infrastructures. TTF7 is concerned with prevention & control of degradation & damage of pressure equipment due to hydrogen effects. This covers high & low temperature service, detection & monitoring of damage and developing an understanding of mechanisms to assist with prediction of future behaviour in existing & new equipment, and where possible, harmonisation of approaches to testing & assessment.

In practice, the activities of TTF7 have been shaping into a number of working groups, or areas of competences, each co-ordinated by one member, who acts as a contact person, as well as discussion leader in the relevant panel at TTF7 meetings. In this sense, at the 3rd TTF7 meeting (FORCE Institute in Denmark in June 2001), it was agreed that the asset of TTF7 consists of two "vertical" tasks, namely Heavy Wall Reactors and HIC-SOHIC, and three horizontal tasks, i.e. Inspection, Permeation and Welding & Repair. Action in the horizontal tasks are essentially be finalized to support the activities in the vertical tasks, while exploring eventual possibilities to develop autonomous projects.

Action in the vertical tasks is on-going in the form of:

- drafting work programmes for the preparation of Guidelines relevant to the operation and repair of hydrotreating reactors, a lack in this sense existing with the current European Codes.
- preparing a survey on Field experience of SOHIC in wet H_2S, jointly with the European Federation of Corrosion. This will have a quite large base and is meant to be the base for an EPERC bulletin eventually preparing the way for a TTF7 research project in this field.

With specific reference to inspection, TTF7 has undertaken an action, joint with TTF3, in order to identify and prioritise the R&D needs of industry in terms of inspection and monitoring of hydrogen damage. The preliminary results of this survey, which are now available, seem to indicate that inspection and monitoring of hydrogen damage constitutes a relatively specialised field in which well-identified R&D needs seem to exist. Most of the potential in this are lies apparently in the upgrade of existing technologies through collaborative projects aimed at developing new techniques & standards.

EPERC TTF7
Hydrogen Damage

MPA Stuttgart 5th Oct 2001

Overview of TTF7 activities

R. Koers, P. Castello

EPERC Workshop on

In-Service Inspection and Life Management of Pressure Equipment

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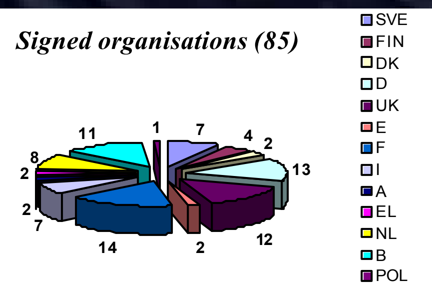
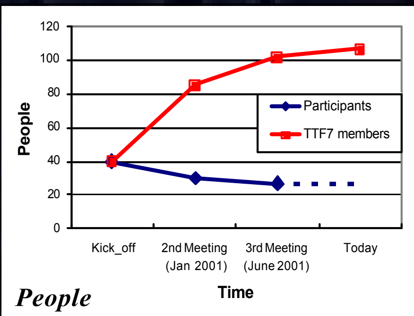
EPERC TTF7
Hydrogen Damage

TTF7 Status (October 2001)

Signed organisations (85)



Approaching steady state



People

EPERC TTF7
Hydrogen Damage

TTF7 Activities

Heavy Wall Reactors	SOHIC
• Guidelines for hydrotreaters • Disbonding test standardisation	(Stress-Oriented Hydrogen Induced Cracking) • Survey on field experience (with EFC)

Inspection and monitoring
Survey on Inspection and monitoring of Hydrogen Damage (with TTF3)

Permeation
Competence Group – *(Ion Science Ltd. - UK)*

Welding and Repair
Competence Group – *(BAM - D)*

EPERC TTF7
Hydrogen Damage

Inspection and monitoring

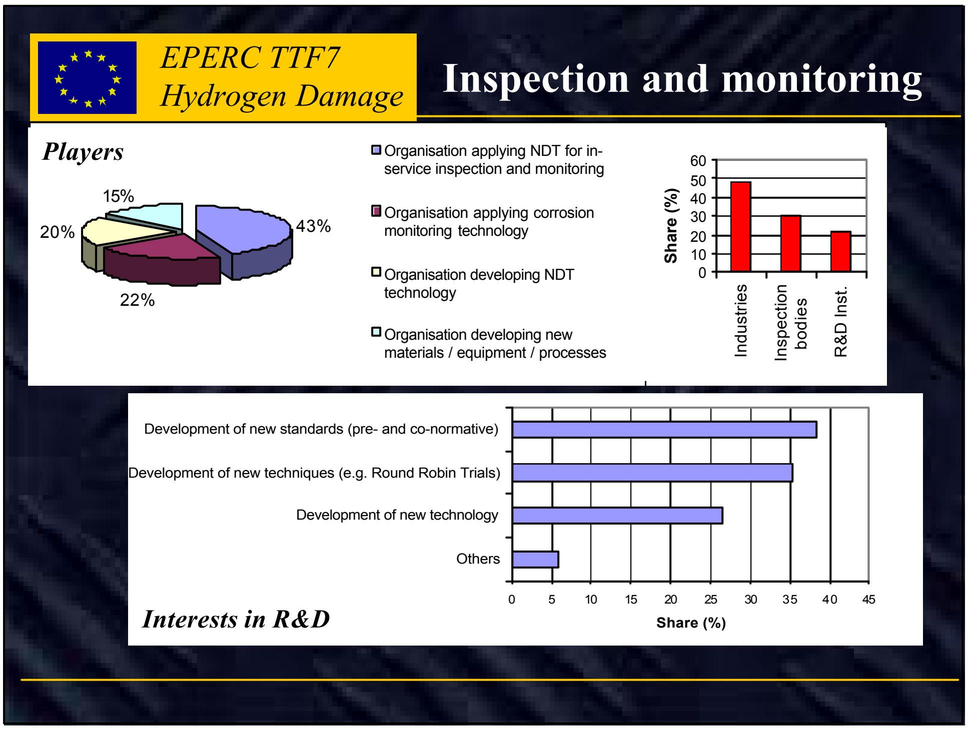
Survey on Inspection and monitoring of Hydrogen Damage

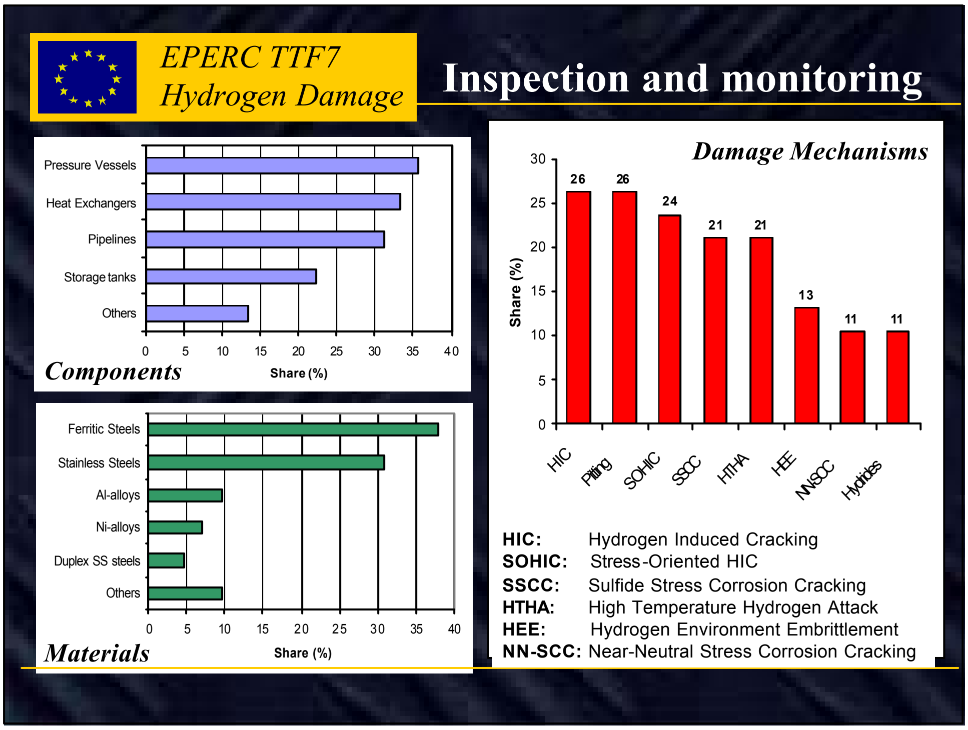
Leading Authors:
G. Dobmann, TTF7, Fraunhofer IZFP, Saarbrücken (D)
A. Eriksson, TTF3, JRC/IE Petten (NL)

Purpose:
Identify R&D needs in view of future Research Projects

Distribution:
All EPERC Members + selected group of non- EPERC Members

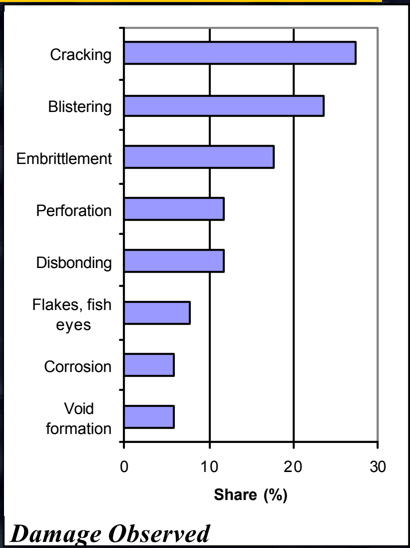
Response rate: 14% *(fairly bad)*
Interest in future R&D: 82% of responses
=
23 organisations *(fairly good)*

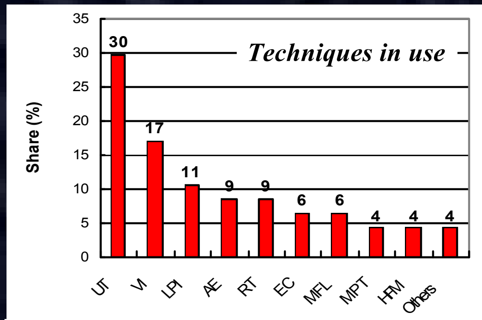

EPERC TTF7
Hydrogen Damage
Inspection and monitoring
Players
15%
20%
43%
22%
Organisation applying NDT for in-service inspection and monitoring
Organisation applying corrosion monitoring technology
Organisation developing NDT technology
Organisation developing new materials / equipment / processes
Share (%)
60
50
40
30
20
10
0
Industries
Inspection bodies
R&D Inst.
Development of new standards (pre- and co-normative)
Development of new techniques (e.g. Round Robin Trials)
Development of new technology
Others
0 5 10 15 20 25 30 35 40 45
Share (%)
Interests in R&D


EPERC TTF7
Hydrogen Damage
Inspection and monitoring
Pressure Vessels
Heat Exchangers
Pipelines
Storage tanks
Others
0 5 10 15 20 25 30 35 40
Components
Share (%)
Ferritic Steels
Stainless Steels
Al-alloys
Ni-alloys
Duplex SS steels
Others
0 5 10 15 20 25 30 35 40
Materials
Share (%)
Damage Mechanisms
Share (%)
30
25
20
15
10
5
0
26
26
24
21
21
13
11
11
HIC
Pitting
SOHIC
SSCC
HTHA
HEE
NNSCC
Hydrides
HIC: Hydrogen Induced Cracking
SOHIC: Stress-Oriented HIC
SSCC: Sulfide Stress Corrosion Cracking
HTHA: High Temperature Hydrogen Attack
HEE: Hydrogen Environment Embrittlement
NN-SCC: Near-Neutral Stress Corrosion Cracking

EPERC TTF7
Hydrogen Damage

Inspection and monitoring





UT: Ultrasonic Testing
VI: Visual Inspection
LPI: Liquid Penetrant Inspection
AE: Acoustic Emission
RT: Radiographic Testing
EC: Eddy Current Testing
MFL: Magnetic Flux Leakage Testing
MPT: Magnetic Particle Testing
HFM: Hydrogen Flux Monitoring

EPERC TTF7
Hydrogen Damage

Preliminary conclusions

- Inspection and monitoring of hydrogen damage can be regarded as a **relatively specialised domain** in which, however, further developments are felt as needed.
- More than 70% of the potential in this domain lies apparently in the **optimisation of established techniques** rather than in the development of new technologies.
- **Generalized technical rules and consensus in understanding**, (interpretation of the potentials and reliability in terms of damage parameters) are missing.
- Detailed discussions among potential partners must follow on the objectives of a future **round robin** and **pre-normative work** to prepare standardization.

4.2. G. Dobmann, S. Hirsekorn and U. Netzelmann
Limits of Ultrasonic Backscattering and Phase Velocity Measurement for the Non-destructive Characterization of Hydrogen Attack – Numerical Simulation for Technical Justification

- *Presentation*

Limits of Ultrasonic Backscattering and Phase Velocity Measurement for the Non-destructive Characterization of Hydrogen Attack – Numerical Simulation for Technical Justification

G. Dobmann, S. Hirsekorn and U. Netzelmann

EPERC TTF 3, 5 and 7

Stuttgart, October 5, 2001

In-Service Inspection and Life
Management of Pressure Equipment

Outline:

- Introduction
- Numerical Prediction of Ultrasonic Effects indicating Damage
  - Scattering Coefficients
  - Phase Velocities
- Experimental Verification
- Conclusions

In-Service Inspection and Life Management of Pressure Equipment

Introduction:

- Homogeneously distributed voids (creep damage, pores) and microcracks reduce the velocities of sound
- For small volume fractions of pores the relation is linear
- The decrease in v_l is stronger than for v_s
- Hasegava and independently Birring et al found by experiments that v_s/v_l should be an ‚precursor' for damage if the value exceeds 0.55 (in undamaged material the value is 0.54)

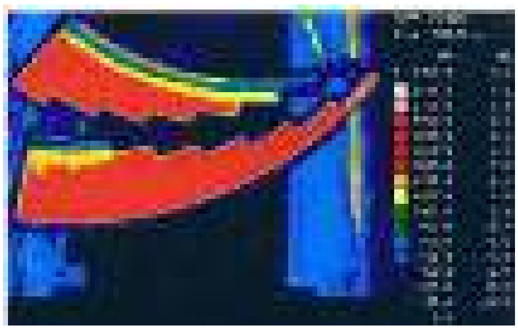
In-Service Inspection and Life Management of Pressure Equipment

In-Service Inspection and Life Management of Pressure Equipment

Fraunhofer Institut Zerstörungsfreie Prüfverfahren

EPERC

In-Service Inspection and Life Management of Pressure Equipment



C-scan of damaged samples, sound Incidence in axial pipe direction; sample IV-IA upper part, sample IV-IB lower part; the UT backwall echo is visualized, yellow colour = high attenuation.

Fraunhofer Institut Zerstörungsfreie Prüfverfahren

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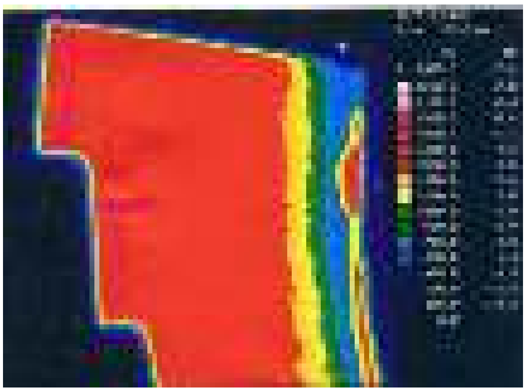
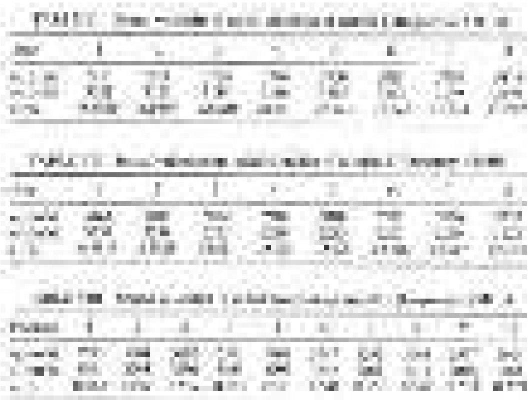
In-Service Inspection and Life Management of Pressure Equipment

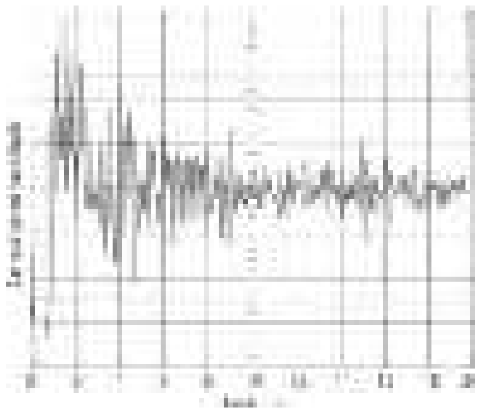


C-scan of the thick end of the sample, Axial sound incidence; sample IV-IA, more than 10 db attenuation near the id surface.

In-Service Inspection and Life Management of Pressure Equipment



In-Service Inspection and Life Management of Pressure Equipment



Backscattering signal od sample IV-IB, insonification from the id surface.

IZFP Fraunhofer Institut Zerstörungsfreie Prüfverfahren

EPERC

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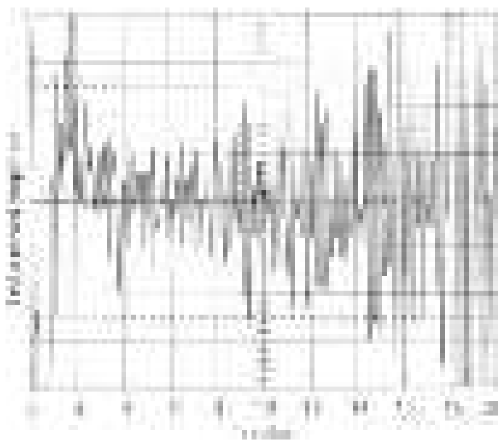
In-Service Inspection and Life Management of Pressure Equipment



Backscattering singnal of sample IV-IA; insonification from od surface.

IZFP Fraunhofer Institut Zerstörungsfreie Prüfverfahren

EPERC

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In-Service Inspection and Life Management of Pressure Equipment

In-Service Inspection and Life Management of Pressure Equipment

Conclusion (1):

- The work was sponsored by Shell Research; corresponding author: P.W. van Andel, Zevenaar Electronics & Sensoren, Shellenkrans 23, 6904 PS Zevenaar
- See: S. Hirsekorn et al;Nondestr. Test. Eval., Vol. 15, pp. 373 – 393, 2000
- Velocity measurements - in most of the cases – do not yield sufficient quantitative information to damage ; variations of velocity in undamaged material with probe position (microstructure inhomogeneities) are often larger than thos caused by damage

Conclusion (2):

- US-attenuation is clearly increasing in damaged volume fractions
- Therefore also the backscattering amplitude is increased; the contrast enhancement is especially high for insonification from od surface and damage position at the id surface.

4.3. F. Bresciani, F. Peri
Non intrusive inspection methods and assessment criteria adopted for SSC, HIC and SOHIC detection: experience of IIS

- *Abstract*
- *Presentation*

NON-INTRUSIVE INSPECTION METHODS AND ASSESSMENT CRITERIA ADOPTED FOR SSC, HIC AND SOHIC DETECTION: EXPERIENCE OF IIS

F. Bresciani and F. Peri
Istituto Italiano della Saldatura

Abstract

This paper deals with the procedures that IIS (Istituto Italiano della Saldatura) has defined to inspect equipment subject to H_2S wet.
In the last three years IIS has inspected more than 300 refinery pressure vessels in order to detect H_2S wet damage and has set up for this purpose two detailed procedures: the first one for the definition of the critical level of damage and the second one for the NDT examination.

<u>Procedure for the definition of the critical level of damage</u>
The scope of this procedure is the definition of the criteria to assess the damage susceptibility before performing NDT and therefore to establish the extension of NDT inspection. Beside this procedure contains the criteria for assessing the stability of defects and the criteria for the final evaluation and for the frequency of future inspections.
The susceptibility is defined on the basis of the material properties, the severity of the process and it is also affected by the previous inspections.
According to the susceptibility level of the component, IIS defines a specific inspection program; the results of the inspection and, if necessary, a fitness for service evaluation, lead to a rank of criticism of the component and to the definition of the subsequent inspection interval.

<u>Procedure for the NDT examination</u>
This procedure explains the NDT methods and their technique in case of both internal inspection and external inspection.
The external inspection is based essentially on a ultrasonic inspection both on welds and on base material.
Instead, internal inspection foresees both magnetic particle testing and visual inspection in addition to ultrasonic testing.

NON INTRUSIVE INSPECTION METHODS AND ASSESSMENT CRITERIA ADOPTED FOR SSC, HIC AND SOHIC DETECTION:

EXPERIENCE OF IIS

F. Bresciani and F. Peri

1

ISTITUTO ITALIANO DELLA SALDATURA
(Italian Institute of Welding)
has inspected more than 300 refinery pressure vessels in the last three years in order to detect H_2S wet damage

IIS has set up for this purpose two detailed procedures:

- for the definition of the critical level of damage
- for the NDT examination

2

IIS procedure for the definition of the critical level of damage

The scope of this procedure is to define:

- criteria to establish the damage susceptibility before NDT and to establish the extension of NDT inspection
- criteria to assess the defect criticism
- criteria for the equipment final evaluation
- criteria for the frequency of future inspection

3

IIS procedure for NDT examination

The scope of this procedure is to define:

- NDT methods and their techniques for detection of wet H_2S damage both in case of internal inspection and in case of external inspection.

4

IIS procedure for the definition of the critical level of damage

CRITICISTERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

The evaluation of the damage susceptibility (GSD) may be performed for SSC, HIC and SOHIC damage according to:

Thickness (mm)	Tensile strength Rm (Mpa)	Evaluation for SSC	Evaluation for HIC SOHIC
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

(*) [illegible]

IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

For any typology of damage (SSC, HIC, SOHIC) IIS defines:

- Process severity (SP)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

example for SSC

IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

- Damage susceptibility (SD)

[illegible]	[illegible]			[illegible]		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

example for HIC- SOHIC

7

IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

- Preliminary severity index (SIP)

[illegible]	[illegible]
[illegible]	100
[illegible]	10
LOW	1
[illegible]	1

This index is corrected in function of the operating condition

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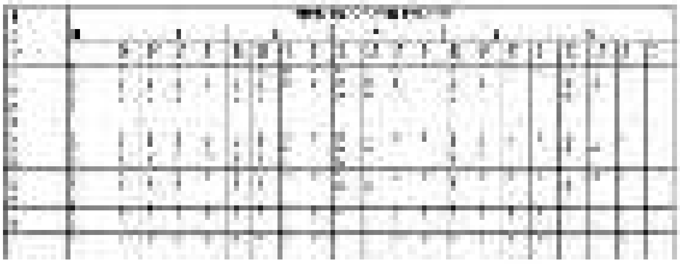
IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

- Preliminary severity index (SIP)

If the equipment has been examined in the past, SIP can be reduced according to the inspection effectiveness



SIP =SIP (table) X (n° years from the last inspection)$^{1.1}$

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IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE DAMAGE SUSCEPTIBILITY

- Category of preliminary likelihood of damage(CPDP)

1: low
2: medium
3: high

10

IIS procedure for the definition of the critical level of damage

CRITERIA TO ESTABILISH THE EXTENSION OF NDT

example for HIC - SOHIC

11

IIS procedure for the definition of the critical level of damage

CLASSIFICATION OF DEFECTS

SSC
- longitudinal cracks in HAZ
- transversal cracks in weld metal

12

IIS procedure for the definition of the critical level of damage

CLASSIFICATION OF DEFECTS

LAMINATION

-L1: planar indication localised at a fixed depth
$H_{echo} \leq FBH\ 3$

-L2: planar indication localised at a fixed depth
$FBH\ 3 < H_{echo} \leq FBH\ 5$

-L3: planar indication localised at a fixed depth
$FBH\ 5 < H_{echo} \leq \infty$

-L4: $H_{echo} = \infty$. Presence of backwall Eco

-L5: $H_{echo} = \infty$. Absence of backwall Eco

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IIS procedure for the definition of the critical level of damage

CLASSIFICATION OF DEFECTS

BLISTERING

-B1: internal or external blister. Absence of backwall echo. Absence of cracks near the edge.

-B2: internal or external blister. Absence of backwall echo. Presence of cracks near the edge.

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IIS procedure for the definition of the critical level of damage

CLASSIFICATION OF DEFECTS

HIC

- stepwise internal cracks that connect adjacent hydrogen blisters on different planes in the metal or in the metal surface. It is possible to find them with shear waves.

SOHIC

- array of cracks, aligned nearly perpendicular to the stress, that are formed by link -up of small HIC cracks in steel. It is possible to find them with shear waves.

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IIS procedure for the definition of the critical level of damage

CRITERIA TO CALCULATE THE CRITICISM OF DEFECTS

The criteria are fixed for every type of damage

For example for SSC - HIC - SOHIC

- At the beginning, calculation according to:
level 1 BS 7910/99 or level 2 API579

- If the flaw dimensions are greater than 50% of the allowable value then a new calculation will be done according to: level 2 BS 7910/99 or level 1 API579

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IIS procedure for the definition of the critical level of damage

CRITERIA FOR THE FINAL EVALUATION OF THE EQUIPMENT

As consequence of the calculations IIS defines

- for SSC:
  - 5 different classes of criticism of equipment (A-B-C-D-E)
- for HIC - SOHIC
  - 7 different classes of criticism of equipment (A-B-C-D-E- F-G-H)

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IIS procedure for the definition of the critical level of damage

CRITERIA FOR THE PERIODICITY OF FUTURE INSPECTIONS

The future inspections are defined according to the class of criticism

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

example for HIC - SOHIC

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IIS procedure for the definition of the critical level of damage

CRITERIA FOR THE FREQUENCY OF FUTURE INSPECTIONS

If the equipment must be repaired or replaced or if NDT doesn’t find any defect
IIS defines a Category of final likelihood of damage(CPDF) correlated with the frequency of future inspection

example for HIC - SOHGIC

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IIS procedure for NDT examination

TYPE OF INSPECTION

IIS applies two different type of inspection:

EXTERNAL INSPECTION (when the equipment works):
- visual inspection
- ultrasonic testing on welds and on base material

INTERNAL INSPECTION :
- visual inspection (internal)
- magnetic particle testing (internal)
- ultrasonic testing on welds and on base material (internal or external)

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IIS procedure for NDT examination

ULTRASONIC TESTING

Both for internal and for external inspection:

Inspection of welds and base material near welds:
- butt welds (longitudinal, circular, nozzle, appendix, etc)
- fillet welds

Inspection of base material far from welds (HIC -SOHIC)
- an area on every shell plate
- an area on every dome plate

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IIS procedure for NDT examination

ULTRASONIC TESTING
PROBES

Research of lamination and blistering

- **Straight beam probes with separate transmitter and receiver elements. Frequency: 4 - 5 MHz**

Research of HIC - SOHIC

- **Straight beam probes with separate transmitter and receiver elements. Frequency: 4 - 5 MHz**
- **Angle beam probe with 45° angle of incidence (in some cases could be necessary to use 60° and 70° too). Frequency: 4 - 5 MHz**

Research of SSC

- **Angle beam probe (angles in function of thickness). Frequency: 4 - 5 MHz**

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CONCLUSIONS

IIS, IN THESE LAST 3 YEARS, HAS MONITORED MORE THAN 300 EQUIPMENT:

- **10 -15% OF THEM HAVE DEFECTS WHICH REQUIRE FUTURE MONITORING**
- **1-2% OF THEM NEED TO BE REPAIRED OR REPLACED**

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4.4. F.-W. Bach, K.L. Feiste, W. Reimche and W.Weber: Perspectives for the determination of hydrogen induced material degradation with electromagnetic inspection techniques

- *Abstract*
- *Presentation*

PERSPECTIVES FOR THE DETERMINATION OF HYDROGEN INDUCED MATERIAL DEGRADATION WITH ELECTROMAGNETIC INSPECTION TECHNIQUES

Bach, F.-W.; Feiste, K.L.; Reimche, W.; Weber, W.
Institute for Material Science - Department of Non Destructive Testing IW-ZFP
University of Hannover

Abstract

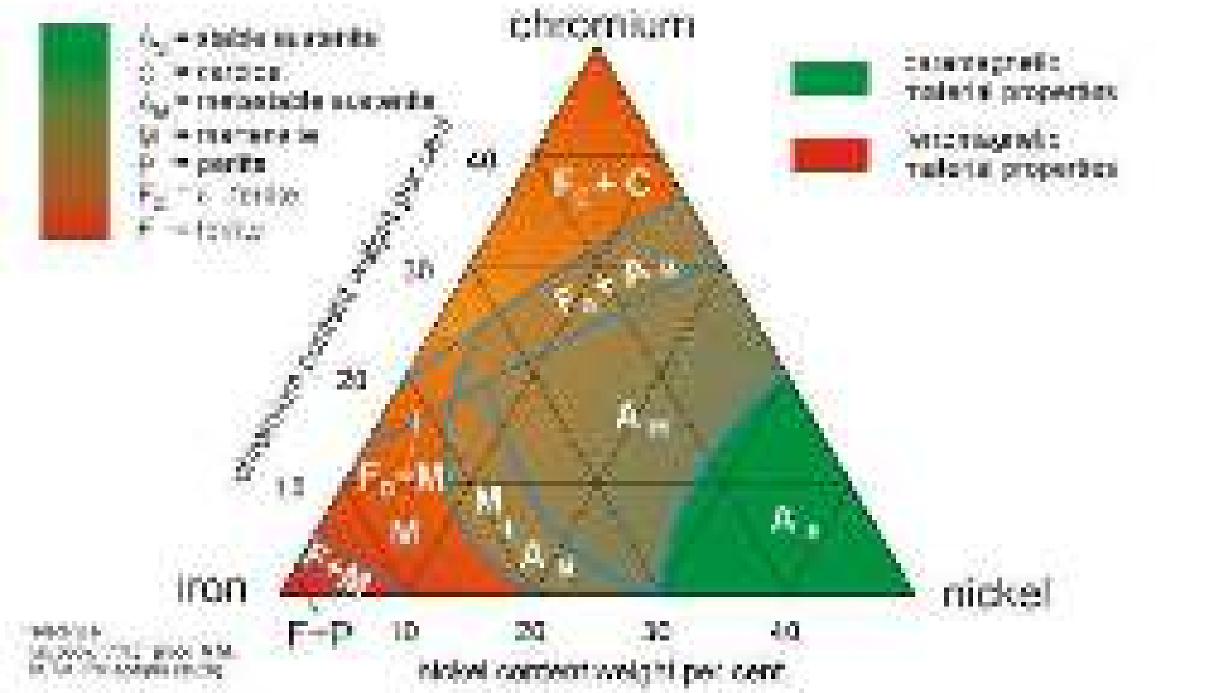
Hydrogen induced damages inside of industrial used components are indicated by material embrittlement and material separation. Non destructive testing techniques for determination of this kind of damages are an important contribution for safe operation. Due to their electromagnetic properties, industrial used steels can be classified into groups of ferromagnetic and paramagnetic materials. Regarding this properties, the electromagnetic testing techniques for material characterisation and defect detection have to be adapted.

For sensible types of steel, the load of hydrogen causes crystal lattice distortions, which are responsible for development of residual stresses or defects inside the material.

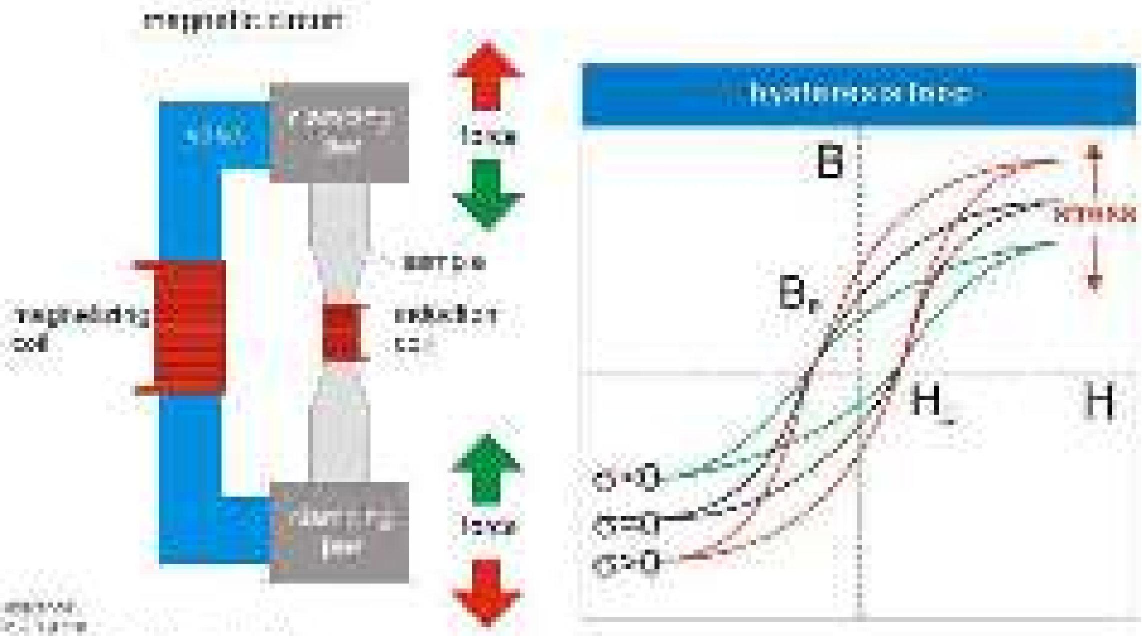
Due to the effect of magnetostriction, the magnetic hysteresis of ferromagnetic steels is influenced by the inner material stress conditions. The change of ferromagnetic behaviour caused by hydrogen induced stress can be detected by use of electromagnetic testing techniques.

Corresponding to the alloy composition of chromium nickel steels, a wide range of variations from pure paramagnetic up to pure ferromagnetic behaviour can be established. Under stress conditions, metastable stainless steel tends to transformations of paramagnetic into ferromagnetic phases. Crack initialisations are caused by high local stress concentrations which are accompanied by significantly increased ferromagnetic behaviour. By this, critical areas inside of industrial used components made of metastable stainless steel can be detected by monitoring increased ferromagnetic material properties.

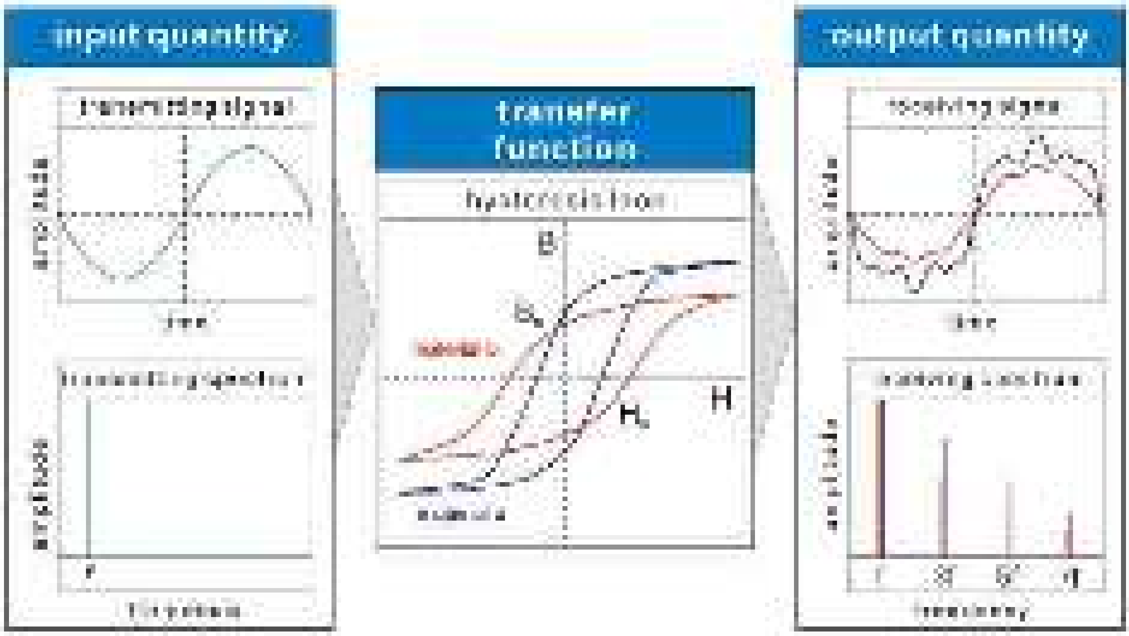
To demonstrate the perspectives for determination of hydrogen induced material degradation, results of investigations carried out in the field of stress determination on ferromagnetic materials using electromagnetic testing techniques will be presented. Furthermore, the sensitivity of electromagnetic testing techniques to phase transformations inside of metastable stainless steels caused by stress will be demonstrated.



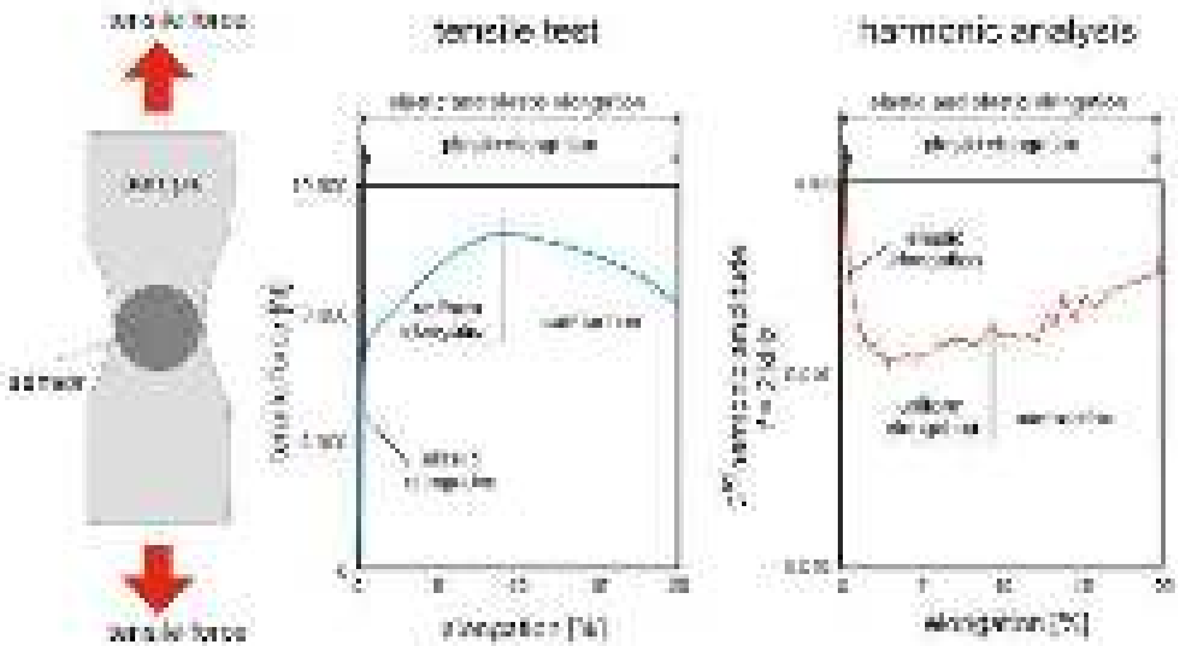
Classification of Magnetic Properties Due to Alloy Elements



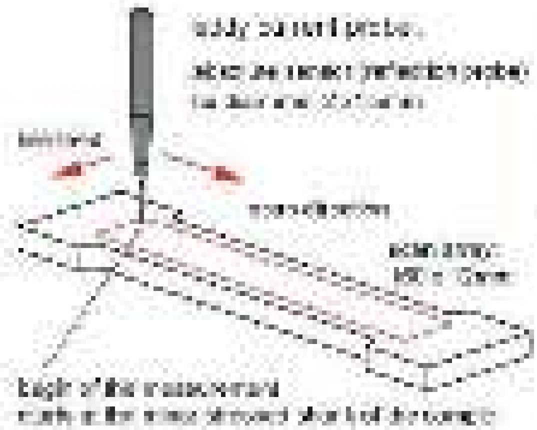
Influence of Mechanical Stress on Ferromagnetic Magnetic Properties



Model of Harmonic Origin



Amplitude of 3rd Harmonic



parameter:

X 5 CrNi 18 10 (1.4301)

metastable austenitic material

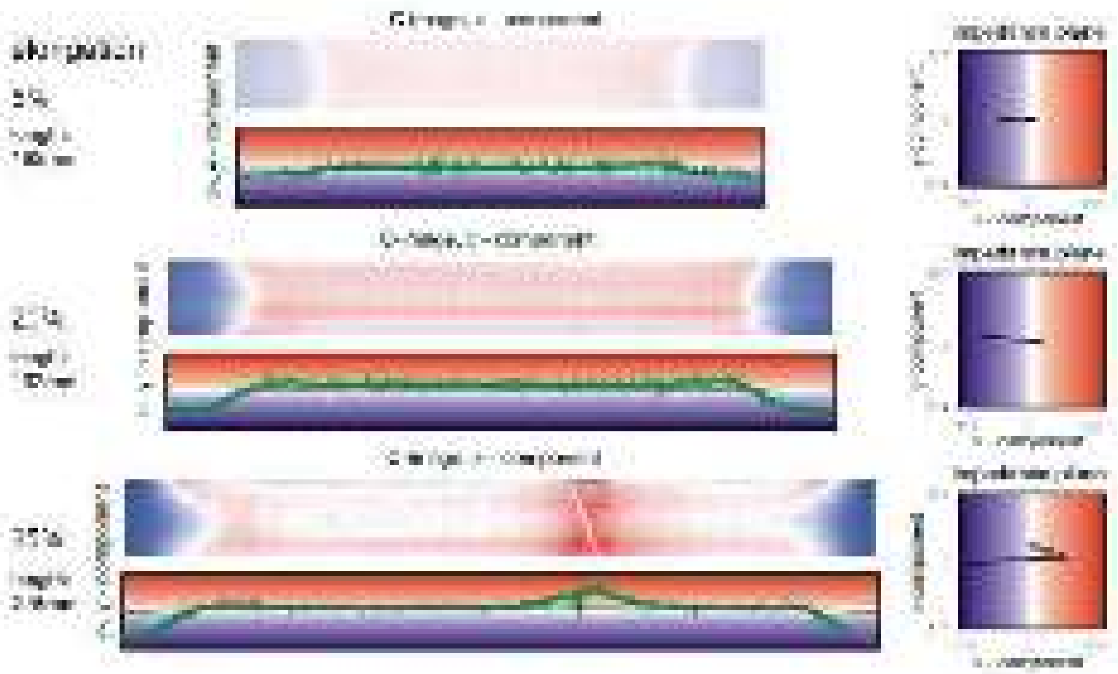
chemical composition:

C	Si	Mn	P	S	Cr	Mo	Ni
0.05	0.42	1.35	0.027	0.004	18.2	0.2	[illegible]

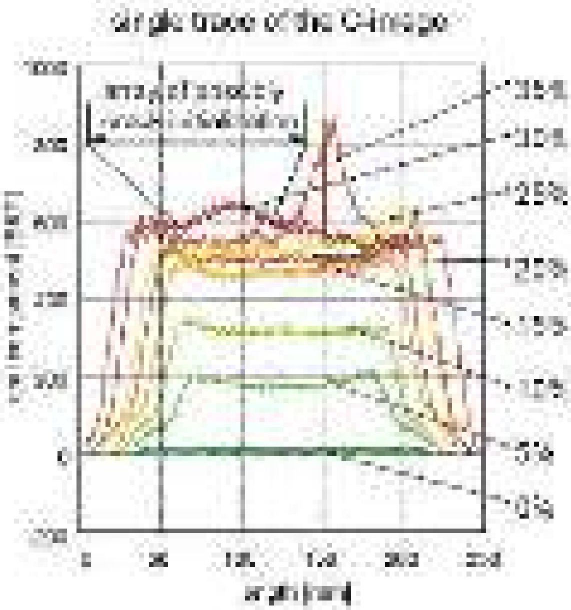
sample preparation:

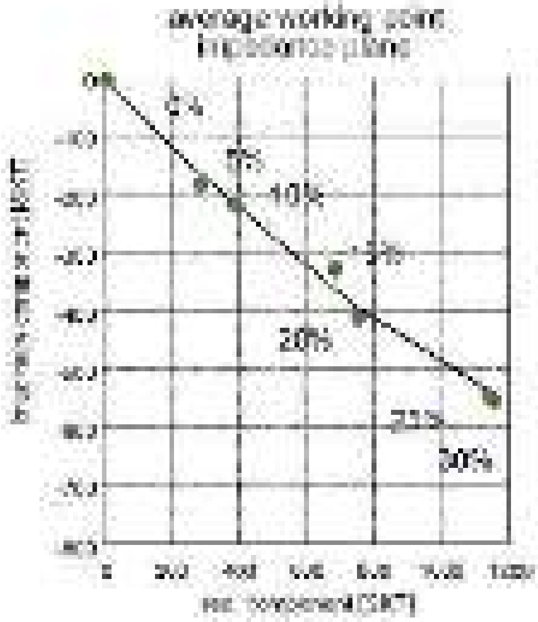
- determination of the tensile strength and the maximal elongation of the material
- scaling of the stepwise plastic elongation of the material 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%
- eddy current measurements are done at unloaded samples

High Resolution Eddy Current Measurements of Magnetic Properties
due to plastic elongation

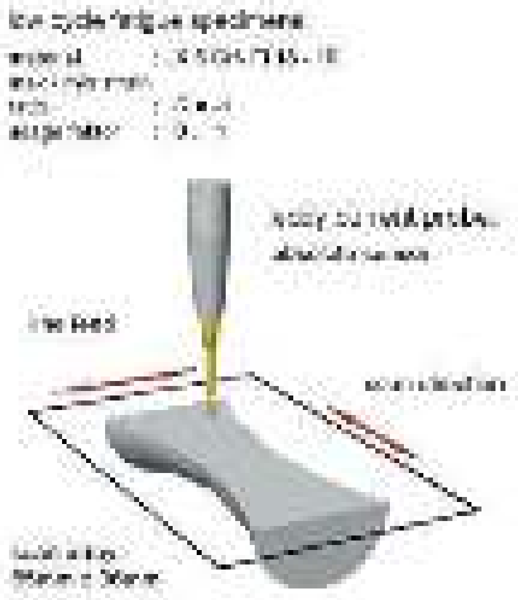


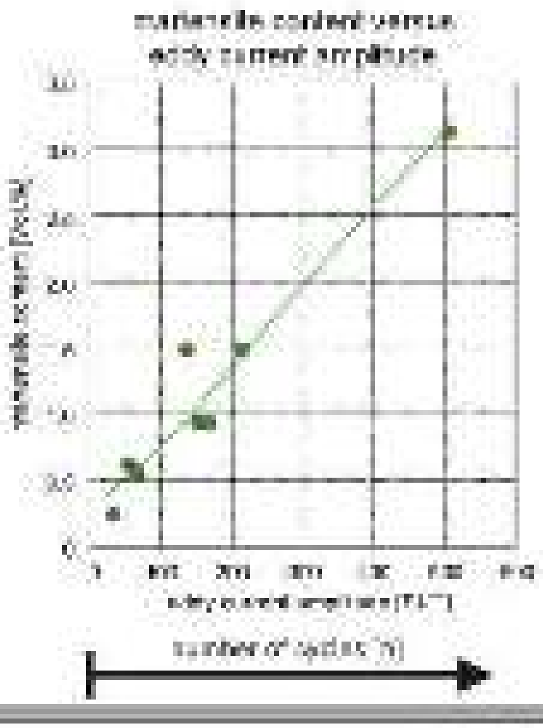
C-Image of Plastic Deformed Tensile Test Samples





Eddy Current Signals versus Plastic Elongation





Determination of Martensite Content with Electromagnetic Methods

Additional Information

Venue

Site of the MPA Seminar
Pfaffenwaldring 47, Room 47.05 (Room No. 3),
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