SYNTHESIS REPORT FOR PUBLICATION

Contract No:	BRPR-CT95-0128
Project No:	BE-1702
Title:	Validation, Expansion and Standardisation of Procedures for High Temperature Defect Assessment (HIDA)
Project Co-Ordinator:	ERA Technology Limited
Partners:	ERA, Imperial College (IC), SPG, MPA, **CEA**, EdF, SAQ/DNV, ENEL, Petrogal (Pet), Metsearch (Mets), Framatome (FRA)
Reference Period From:	January 1996 to December 1999
Starting Date:	January 1996 **Duration:** Four Years
Date of Issue of This Report:	July 2000

Project funded by the European Community Under the Industrial & Materials Technologies Programme (Brite-EuRam IV)

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1. Summary

1.1 Key Words

High Temperature Crack Assessment Procedures, Knowledge-Based-System, Creep/Fatigue Crack Growth, Databank, Life Assessment.

1.2 Project Results and Benefits

The HIDA project has resulted in the development of a draft ‘HIDA Procedure’ which is a unified and software based (or Knowledge-Based) European high temperature crack assessment procedure. It is a unified Procedure as its development has involved partners from a number of European countries who used the knowledge of their own country procedures/ codes to develop this procedure. This Procedure is expected to lead to the establishment of a European Standard. The Procedure is aimed at underwriting the structural integrity and fitness for purpose of all types of (cracked) industrial components operating at high temperatures (within the creep range) under steady state (creep) or fluctuating (fatigue) stresses. The HIDA Procedure is a simplified methodology for crack assessment and is based on both the validated methodologies of the existing European Procedures and those developed through the project.

Five materials from ferritic through martensitic to austenitic steels were tested. These were P22 (or 2.25Cr1MoV), P91, 316 Stainless Steel, 1CrMoV steel for forgings, and 1CrMoV steel for castings. A comprehensive programme of lab specimen and diverse range of feature specimen tests was undertaken to assess crack initiation and growth criteria and their applicability under steady and cyclic loading conditions. A large database of tests from the non-HIDA published and un-published sources has also been put together and scatter bands established for a number of high temperature plant materials and their weldments.

The HIDA Procedure provides a route for crack assessment in industrial components through the use of a Knowledge Based System. It also provides a large amount of materials data and guidance on how and where to use it.

The direct industrial need of end-users in respect of a validated and easy to use defect assessment procedure, (HIDA Procedure), is to improve the capability of extending the useful life of components and in particular to enhance the decision making process in run/repair/replace situations enabling the development of cost effective maintenance and plant rehabilitation strategies. The HIDA Procedure is useful in reducing risk in high temperature plant due to unstable fracture by taking appropriate safety precautions early in time. The Procedure also points out the situations where the use of existing procedures leads to a high degree of conservatism.

Industrial targets for the HIDA Procedure are to achieve reductions in production costs by reducing the frequency of unplanned outages, increasing the operating periods between scheduled inspections, increasing plant availability and efficiency and avoiding the costs associated with the replacement of expensive high temperature components.

Initially, the achievements of the project will be directly applicable to the steels studied. Of these, the tubing and piping steels P22, AISI 316 Stainless Steel and the 1CrMoV rotor and casing steels are amongst the most commonly used high temperature materials within the power generation, nuclear, chemical, process and oil refining industries. The fifth steel studied viz ASTM P91 is a newly developed steel for advanced applications (higher temperatures and pressures) for which currently little data are available.

The deliverables of the project are: a) The HIDA Procedure, b) The KBS or Knowledge Based System which is a software version of the HIDA Procedure, and c) a Databank on creep and fatigue crack growth in high temperature plant components and cracking in industrial components.

2. The Consortium

2.1 Partner Organisations

Co-ordinator of the 'HIDA Project' ERA Technology

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ERA Technology Ltd is a UK based company providing independent contract research and development service to a wide range of industry worldwide. The company has been involved in high temperature materials design and performance evaluation since the 1920s, having possessed its own high temperature materials testing laboratory in 1961. Thereafter, ERA has gained considerable expertise on high temperature design and structural integrity of engineering materials and components through the management of research programmes covering a wide range of industrial applications. Studies have involved computer based metallurgical modelling of high temperature degradation phenomena including creep and fatigue. Work has been carried out in the area of remanent life assessment since the mid 1970's with many utilities and petrochemical companies worldwide. Since 1979, ERA has initiated and co-ordinated internationally supported multiclient R&D projects aimed at providing a basis for improved accuracy in remanent life prediction of power generation and petrochemical plants.

* Dr I A Shibli is also co-ordinator of the post project 'Interest Group' proposed by ENEL

The **Plant and Power Engineering Division** performing Tasks in this project has 30 staff, mostly engineers and metallurgists, with background in plant assessment, high temperature materials technology, fracture mechanics and engineering and structural dynamics. The Division is involved in research programmes that address topics such as creep and thermo-mechanical fatigue crack growth, NDE, high temperature life assessment, component testing, structural design and FE analysis. The latter is facilitated by extensive computing capabilities including workstations utilising ABAQUS and ANSYS software. ERA has specialised expertise in the use of UK defect assessment procedures, with a staff which has a background in fossil, nuclear and petrochemical industry defect and life assessment. Since 1986 the Plant Engineering Division has been involved in over 14 major Brite-Euram projects and acted as Technical Co-ordinator for 8.

Major Tasks

Task 3 : Test Techniques Standardisation

Task 11 : Pressure Pipe Testing

Task 14 : Data Analysis of seam welded pipes

Task 19 : Demonstration

Imperial College (IC)

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Imperial College is a university of the highest possible level in its teaching and research. Its research portfolio covers the fundamental sciences and applied technologies. It is wide ranging and commands the highest respect in the international arena.

Participation of IC in the HIDA project was of mutual benefit to the university and the other participants. IC has special expertise of high temperature materials creep test techniques, high pressure fatigue failure investigations and finite element analysis. The College is actively involved in the UK High Pressure Testing Association, in the VAMAS creep crack growth programmes and has participated in drafting ASTM E 1457:1992, BSPD 6539:1994 and a code of practice for notched bar creep tests. It has also pioneered the use of neutron diffraction for measuring residual stress distributions non-destructively in components and is leading the VAMAS initiative for preparing a code of practice for making these measurements. At the fundamental level, IC is concerned with modelling the high temperature deformation and fracture behaviour of materials and components using damage mechanics, fracture mechanics and stress analysis techniques. Participation in HIDA has enabled IC to broaden its interaction with industry and apply its knowledge to practical problems.

Major Tasks

Task 1 : Assessment of UK and other European procedures

Task 11 : Pipe ‘C’ Ring Tests

Task 14 : Data Analysis and Finite Element Modelling

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This company is an engineering enterprise with activities in planning, designing, constructing and commissioning of energy plants. The Department for Engineering Services is involved in materials technology, mechanics and sound insulation. The services offered include technical plant assessment, quality and safety control, service life estimation and research. KAB has a very large and well developed creep laboratory and component (pipe) testing facilities. The company designs and manufactures boilers for power stations and thus has high interest in this project.

The Production Department will produce pipe bends and the Service Department will provide plant data from Germany and Eastern Europe for Task 14.

Major Tasks

Task 11 : Pipe Tests (straight and Bend)

Task 12 : Creep/Fatigue Crack Growth Tests

Task 16 : Knowledge Based System

MPA – Stuttgart

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MPA - Staatliche Materialpruefungsanstalt Universitaet Stuttgart - is a research institute affiliated to the University of Stuttgart. The main activities of MPA are addressed to safety analyses, risk and life assessments related to materials, components, structures and systems especially of power and chemical plants. In this area, experience and know how of the institute is based on advanced experimental testing procedures, as well as use and validation of sophisticated engineering methods and modern software and hardware tools. MPA has as mid-term and long-term strategic interest of incorporating the software-based HIDA-results in order to perform sophisticated consultant and engineering analysis in the frame of safety analysis and life assessments of power and chemical plants. MPA gained additional experience by co-operation with SPG and ENEL. MPA's High Temperature R&D department has 30 employees, active in project management, software development, material testing, Finite Element-computation, structural analysis, microstructural characterisation and NDE.

MPA had employed a Department Head, PhD in mechanical engineering with 20 years experience in life assessment of fossil power plants and the project management of experimental and theoretical-numerical investigations, a senior research engineer, PhD with 18 years experience in the development of the KBS and related software tools, mechanical engineer with 15 years experience in creep fracture mechanics and the evaluation of defect behaviour in power plant component, mechanical engineer with experience relating to creep property determination and the evaluation of creep damage behaviour in metals.

<u>Main contribution to, and responsibility for, research tasks</u>

MPA contributed know-how to the project of the industrial requirements associated with life assessments to evaluate defect behaviour of power and chemical plant components. It will also contribute its know-how of project management, (residual) life time calculation of the relevant components, software development, material characterisation and damage quantification. Its major tasks were: provision of test material (Task 4), machining of feature specimens (Task 7), KBS development (Task 16), and some co-ordination (Task 21).

Apart from the R&D 'High Temperature Department' as outlined above, MPA involved its NDE-department and System and Plant Analysis-Department performing inspections and calculating life time of relevant components in German power plants. These departments contributed to the project by providing inputs to the final version of HIDA and co-operated in the exploitation planning by using HIDA.

Major Tasks

Task 11 : Feature Tests on 1CrMoV (cast) and 1CrMoV (forged) steels

Task 12 : Creep/Fatigue Crack Growth Tests

Task 16 : Knowledge Based System

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CEA is an R&D organisation created by the French government in order to promote applications in the industry of nuclear technology. About 15,000 researchers are involved in CEA in different fields going from physical problems, biology to waste processing and power generation. The study will take place in the Direction of Nuclear Reactors (DRN) (~2,000 people) which is involved in reactor development and safety of PWR, FBR, and Fusion reactors.

The Department of Mechanics and Technology (DMT) performs and develops modelistic methods to analyse mechanical and thermal behaviour of reactor components. The code CASTEM 200V is specially developed for such applications.

The service (SEMT) is the location where the study was performed. CASTEM 2000 and the A16 document are developed by experts working at SEMT. They use numerous publications, available in the open literature, showing the developments made in the service of high temperature defect assessment.

Major Tasks

Task 2 : Acquisition and Analysis of Data from other Projects

Task 11 : Large Plate Tests

EDF

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Electricite de France (EDF) is the French national company whose mission is production, transmission and distribution of electricity. At DER (Direction of Studies and Research), the department "Etudee des Materiaux" (Materials Studies - EMA) has been entrusted for more than 20 years with the role of expert having to guarantee the correct in-service behaviour of materials used by the company. Researchers and technicians of this department form the EDF's leader team for this project. But they are working together with other Directions, essentially with the people involved in the classical thermal power plants, belonging to the Direction of Production and Transportation (DEPT).

EDF had much interest in this project. Creep, fatigue and their combination are the most important damage mechanisms in the classical power plants that exist in the French power park and that become quite old. It appeared a few years ago that fatigue is very important due to the numerous start/stop cycles which are now working in a semi-basis scheme, and not any more in a basis scheme, as they were built for.

Major Tasks

Task 1 : Procedure Analysis

Task 2 : Other projects and plant experience

Task 12, 13 : Creep and 'creep fatigue crack growth' tests

Task 14 : Data analysis

DNV (previously SAQ)

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The Swedish Plant Inspection Ltd. DNV is the largest inspection agency (industry) in Sweden with about 600 employees. DNV participated in this project as a developer and end-user.

DNV is a company specialising in safety inspection and lifing of appliances and pressurised equipment and a customer base throughout the Swedish industry. To support our core business activity and to solve specific problems of failure avoidance, R&D has a central part in our organisation. DNV's R&D department consists of 16 employees, active in fracture and creep mechanics, material and welding technology. DNV has a strategic interest in developing a more accurate and reliable procedure for high temperature defect assessment.

The sub-contractor SIMR contributed with experimental capacity. SIMR has specialised test facilities and expertise in such testing.

As an end-user DNV had a particular interest in the development of the knowledge based system - KBS (Task 16) and was involved in continuously testing, evaluating and advising MPA on the KBS.

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ENEL is the Italian National Power Utility. At the time of the work ENEL employed about 100,000 workers and is responsible for design, construction and operation of Power plants and for the distribution of electrical energy in Italy. ENEL had a total installed capacity of about 50,000 MW (65% fossil fuelled), with 60 thermal power stations in service. ENEL is also active in R&D for innovative technologies. The ENEL Central Laboratory at Piacenza, the Unit which directly participated in the project, is particularly involved in the assessment of the residual life of in-service components.

The main contribution of ENEL within the proposed project was the result of its extended plant experience; such cases were analysed and fed into the databank (Task 15). Moreover, ENEL conducted creep tests on P91 specimens (Task 13); this included pre and post-test metallography and the analysis of data.

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Petrogal is a leading Portuguese industrial company, size S6, with a total income of about 2500 MECU per year. PETROGAL is the only established company with refineries in Portugal.

PETROGAL's main objectives comprise the exploitation of crude oil and natural gas, refining, transportation, distribution and selling of crude oil in Portugal. PETROGAL also controls on a majority basis the distribution of refined products via its own GALP trademark.

The main role of the partner (PETROGAL) in this project was in Tasks 2, 5, 8 and 10. Petrogal is the petrochemical company chosen to work in this project to increase the multi-sectorial nature of the project. The contribution of data from petrochemical industries to Task 2 enhanced the usefulness and reputability of the new procedures. ISQ is a leading Portuguese R&D, welding and power plant and refinery plant service organisation which acted as a sub-contractor to Petrogal. ISQ contributed to Task 8 (fatigue testing) and Task 10 (NDE). ISQ has expertise in both these fields.

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Partner (METSEARCH B.V) is an SME whose activities started with research, development and testing on materials. The involved personnel expertise include non-destructive evaluation of residual stresses and microstructure, structure - properties correlation, laser material processing, shape memory alloys, intermetallic compounds and alloys for high temperature and corrosion resistance applications, thin ceramic an metallic coatings for wear, corrosion and thermal barrier applications, metal injection moulding to net shape, metal-ceramic joints, SCC of power plant component and pre-stressed reinforcements in concrete, industrial trouble shooting and on-site failure investigations. Metsearch personnel have participated in different European projects. Recently the company is involved in commercial activities on reclaiming and reuse of surgical tools and appliances. The role of METSEARCH B.V. in this project will be in Tasks 9, 10, and 8(a) addressing respectively i) assessment of residual stresses in welds and bends under pre and post creep testing conditions, ii) application of NDE methods to quantify the creep damage prior to cracking and iii) tensile tests at room and elevated temperatures.

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Framatome is a nuclear engineering and heavy component manufacturing company. Framatome performs studies on stress analysis, fatigue behaviour and fracture toughness both in the framework of its industrial activities and in wider R&D context. This has included in the past contract work for customers, programmes sponsored by national and international agencies and active participation in several co-operative BRITE projects.

The company has played an active part (together with CEA and EdF) in developing French procedures. Framatome has much experience in the use of French procedures and has therefore chosen to play a lead role in Task 19 (Demonstration).

2.2 Complementarity, Transnationality and Multi-Disciplinarity of the Consortium

The partnership was highly complementary in that it included research institutions ERA and MPA of international repute, with special expertise in the area of developing codes for life assessment of defect containing components, plant manufacturers (SPG and Framatome), end-users (EDF, ENEL, Petrogal) and a plant inspectorate (SAQ/ DNV). Two other plant manufacturers, Siemens and MAN Energie were also involved as sub-contractors.

The consortium represented a multi-sectorial grouping - thus fossil power generation (ENEL), nuclear industry (EDF and Framatome), atomic energy (CEA), petrochemical industry (Petrogal) are involved. This represented an excellent spectrum of high temperature plant operating industry. This multi-sectorial participation ensured that the new codes are relevant to a broad spectrum of industry.

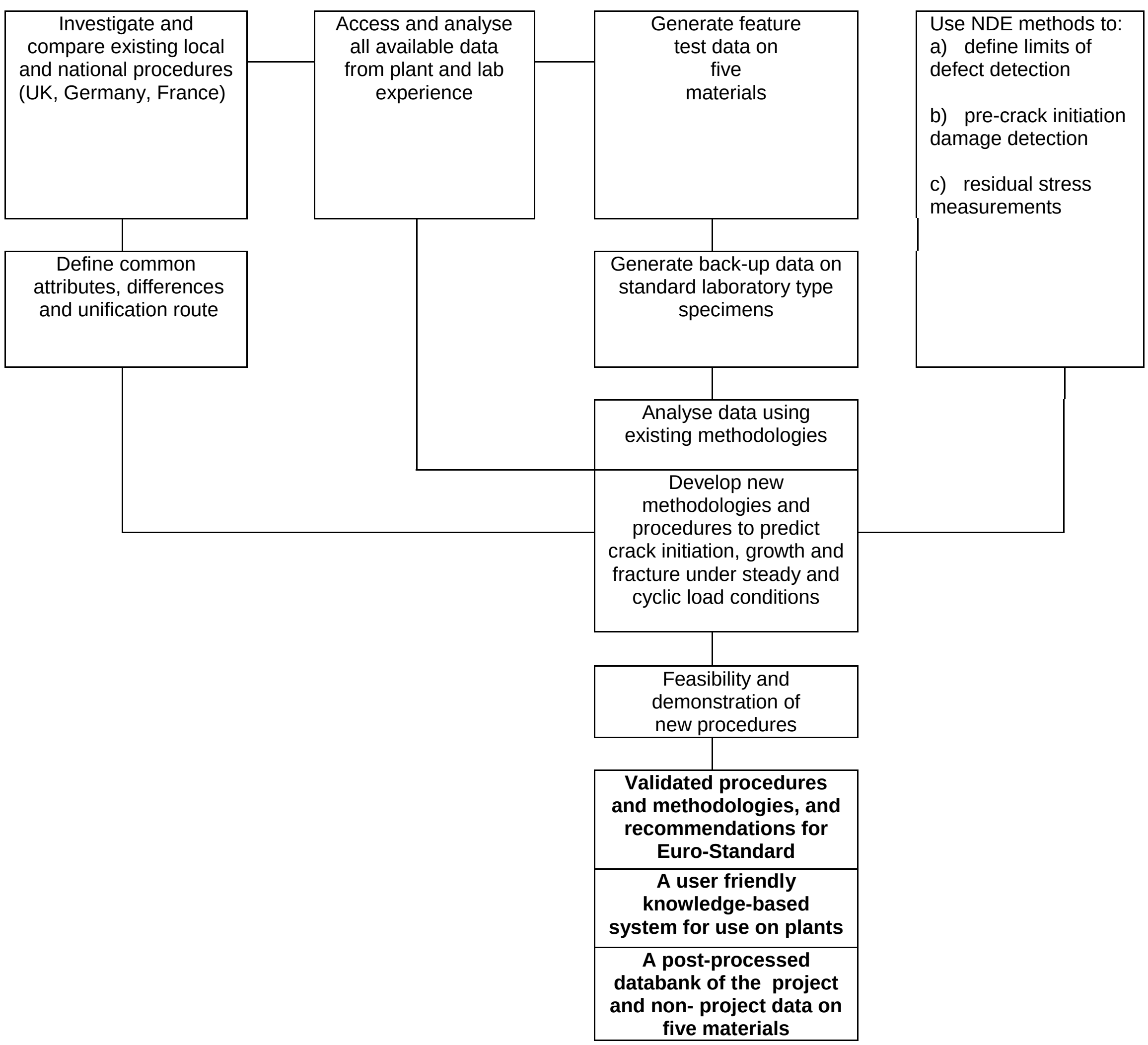
The consortium provided complementary technical skills. Thus Imperial College, MPA, SPG, ERA, FRA and SAQ have well developed skills in mathematical modelling and/or finite element analysis, a number of partners have expertise in feature testing and creep-fatigue crack growth testing, while others have skills in NDE. Metsearch, an SME has been included in the consortium because of its specialised expertise in residual stress measurements.

The presence in the Consortium of a number of end-users from a broad sector of industry had been organised to ensure availability of all necessary plant data and experience which were required to provide credence to the new procedure that this project has developed.

3. Technical Achievements

3.1 Project Methodology

The work and thus achievements of the HIDA Procedure are based on the Project Methodology shown below in a summary form.



The research approach was based on testing five materials (ranging from ferritic through austenitic to martensitic steels) with emphasis on Component or Feature Tests essential for the validation and expansion of existing European defect assessment procedures and practices. This work was supported by baseline or scoping tests using standard laboratory specimens to generate cast specific data. The crack growth testing concentrated on compact tension (CT) specimens of 'standard size' (W=25mm), with some tests on larger size CTs (W=50mm) and on other geometries i.e. SENT (P22, P91) and CCT (316SS, 1CrMoV forged + cast).

The baseline or scoping tensile, uniaxial creep, and fatigue tests were carried out for:

- establishing material constants for creep and Paris Law equations
- determining the effect of specimen size and geometry and correlating with the feature tests.
- developing creep-fatigue algorithms

Tests on heat affected zone (HAZ), and pre-stressed lab and feature test specimens were carried out to study the effect of secondary stresses. NDE methods such as neutron diffraction and X-ray diffraction techniques were used to study residual stress and pre-crack growth damage patterns.

The five test materials covered the broad spectrum of steels used in the fossil and nuclear power plant boilers and turbines, for pipework, and for petrochemical plant reactor vessels.

Creep and fatigue crack growth data on the five materials was also pooled together from published and unpublished sources outside the HIDA work to give lower and upper bounds of crack growth for these materials. Information on in-service component cracking from plant experience was also collated and forms a part of the HIDA Databank and the KBS for further validation of this new European Procedure.

3.2 Material Specific Findings

P22

Tests on this material showed that despite the anisotropy effect from the pipe manufacturing there was no such effect on the material creep rupture, CCG, or CFG characteristics. This was true both for the base and the weld metal constituents.

Pipe tests both at ERA (seam welded) and SPG (butt welded) showed that crack growth in the HAZ could be about 10 times faster than that in the base metal. Low cycling of pipes (one cycle/ 8 hours or 0.001 Hz) did not show adverse effect on crack growth in the HAZ or the base metal. This has good implications on plant cycling or two shifting which is now becoming common in the power generation industry due to increased competition.

In the <u>ex-service</u> P22 weld metal the level of visible cavitation did not exhibit adverse effect on the crack growth rate. This perhaps indicates that the micro-level pre-cavitation damage (not determined but expected in these welds exposed to service conditions for 110000 hours) could be determining the rate of crack growth. Beyond this micro level stage of damage the effect might be minimal.

Pipe bends showed that in spite of the post-bend heat treatment residual stresses remained high (90 to 190 MPa), and that after testing for between 3600 to about 8500 hours these remained significant (about 100 MPa). However, in the post-test pipes these stresses relaxed through the wall thickness reaching nil value close to mid-thickness position. As the initial notch tip was located close to the mid wall thickness position, this could then explain as to why the CCG behaviour of pipe bends was well predicted by the CT specimen tests on straight pipe material.

P91

Like P22 pipes, tests on P91 pipes also showed that despite the anisotropy effect from the pipe manufacturing there was no such effect in the material uniaxial creep, CCG or CFG characteristics. This was true both for the base and the weld constituents.

This material showed that crack growth in the HAZ could be about 10 times faster than that in the base metal.

Low cycling (one cycle/ 8 hours or 0.001 Hz) of pipes appeared to increase crack growth both in the HAZ and the base metal. This has significant implications on plant cycling or two shifting of new high efficiency plant which use P91 or the older plant where P91 has been used as the replacement material - especially for headers. Ligament cracking due to fatigue is already a familiar phenomenon in low alloy steel headers. Plant cycling or Two Shifting is now becoming common in the power generation industry due to increased competition. So far it has been thought that lower thickness P91 headers will be safer than P22 headers when subjected to two shifting operation. Experience with P91 is limited within Europe. This finding has therefore significant implications on the new European plant or the older plant using P91 as a replacement steel.

In the case of both the steady and cyclic load pipe tests the crack originally located in the centre of the HAZ moved towards the type IV position. This has implications for the P91 long term performance in that the Type IV cracking can make a material vulnerable to early failure.

Pipe bends showed that in spite of the post-bend heat treatment residual stresses remained high (~ 150 MPa), and that after testing for between about 1500 to 3000 hours these remained somewhat high (less than 40 MPa). Although, unlike P22 bends, no through wall thickness measurements were carried out in this case, by analogy with P22 bend findings, it can be assumed in the post-test pipes these stresses relax through the wall thickness reaching nil value close to mid-thickness position. This will then explain as to why the CCG behaviour of pipe bends was well predicted by the CT specimen tests.

Overall, the vulnerability of P91 to cyclic operation, its low creep rupture ductility (about 6%) and its vulnerability to Type IV cracking will have serious implications on the long term performance of this steel and therefore warrant further investigations. P91 is a steel that until recently was thought to be a new wonder material. The findings of HIDA and other similar recent results on creep performance of the welded components made from similar steels and higher levels of in-plant oxidation experienced by P91 (EPRI, USA) warrant new evaluation of this material for use in European plant.

316 SS

In the case of this high ductility 316LN stainless steel (creep rupture elongation = about 50 to 70%) only large compact tension specimens with 20% side grooves on each side gave valid results both for CCG and CFG tests. The high ductility gave rise to early relaxation of residual stresses during testing.

1CrMoV (cast) & (forged)

Both of these materials showed a low creep ductility. The cast material showing a slightly lower ductility (12 to 20%) than the forged material (14 to 23%). This was reflected in their CCG rates in that the cast material showed higher rates compared with the forged material.

3.3 Procedural Implications

From the review of the present high temperature crack assessment codes it has emerged that life predictions based only on purely procedural calculations specified by the codes do not necessarily give correct answers. The new HIDA Procedure, as specified in the HIDA KBS, therefore adopts a comprehensive and open approach by recommending a choice of methodologies for the prediction of creep crack initiation and growth based on validated HIDA feature tests. The HIDA Procedure is dependent on the KBS and user experience approach. It is now planned that the information and relevant advice would 'build up' over time from experience gained from future tests and plant experience.

Crack Initiation

For crack initiation a criterion of 0.5mm of crack growth is recommended to make it compatible with the NDE resolution when inspecting on site.

Tests on five materials ranging from ferritic through martensitic to austenitic steels have revealed the following:

- Crack initiation both in creep and fatigue cracking situations can be predicted confidently using the <u>Two Criteria Approach</u>, or, the <u>analytical equation</u> (developed within the HIDA project):

$$t_i = \frac{\Delta a \varepsilon_f^*}{3C^{*0.85}} \qquad (1)$$

where Δa is *in* mm, ε_f^* as a fraction and C^* is in MJ/m^2 h.

In both of the above methods the accuracy of prediction depends on the reference stress values used. In this project it was found that the local reference stress either calculated using FE analysis or approximate analytical solutions predicted the initiation period accurately.

- In the presence of fatigue cycles (up to 0.1 Hz) the above approach also holds true and should be applied.
- The Flat Bottom Hole technique should be applied to characterise a crack size where a cluster or clusters of small size defects are found.

Crack Growth

C* solutions should be applied in all cases. Local reference stress values calculated using FE or analytical solutions should be used to determine reference stress required for C* calculations for components.

In the presence of fatigue where the frequency is below 0.1Hz the same C* parameter as for CCG should be used both for determining the crack initiation time and crack growth rate. At or above 0.1 Hz the Paris Law should be used to determine crack growth rate and linear summation of the creep and fatigue damage should be used to determine damage and life.

Cracks in the Weld Metal and HAZ

Material constants for the weld metal should be used for assessing cracks in welds. However, for *assessing cracks in the HAZ material constants obtained from cross-weld uniaxial specimens* should be used.

Advice on Lab Specimen Size and Geometry

Specimens of compact tension (CT), single edge notch tension (SENT), or centre cracked tension (CCT) type can be used. However, it is advised that, wherever possible, grooving of 10% on each side of the specimen should be used. For materials of higher creep ductility (above about 40%) larger size specimens (CT W-50) should be used and side grooving should be increased to 20% on each side.

Incorporation of Residual Stresses

Residual stresses at the tip of the defect, and not on the surface of the component, should be used in any crack growth rate calculations. The residual stresses can be treated as primary stresses with appropriate averaging to allow for stress relaxation during testing/ operation.

3.4 Conclusions

Improvements to previous crack assessment codes have been suggested in the form of a draft HIDA Procedure, by simplification of the crack assessment methodology. This will also allow the code to be more applicable to a wider range of materials and geometries. In addition this Procedure allows for predicting the initiation/incubation period before the crack starts to grow.

The HIDA KBS provides a large database, options to analyse lab or feature specimen data for design or life assessment, and options to use the HIDA Procedures or other national Procedures which are either inbuilt (such as the Two Criteria Approach) or can be linked to the KBS. Further, the HIDA KBS provides routines for critically comparing approaches by implementing a comprehensive sensitivity analysis for crack initiation and growth. This can give the user additional confidence in the accuracy of the calculations.

Through its large database the KBS provides scatter bands for the five materials studied. It thus provides the user a means of verifying if his/ her data lies within the scatter band, which will give him confidence in the use of his data. In the absence of his own data the user will be able to use the HIDA database's average or lower bound data as suitable for a particular situation.

It must be emphasised that the draft HIDA Procedure is a first step towards the establishment of a new European Procedure. (It is inconceivable that in a four year project a new fully fledged procedure can be developed).

By their very nature the feature tests that can be conducted in a four year programme are of relatively short term duration. A number of factors therefore need to be further studied in a continuous effort to extend and further validate this procedure. Some of these are as follows:

- The HIDA Procedure needs to be validated for crack assessment of real cases in industrial situations. As full material and crack monitoring information will be required for this, it will therefore require a systematic and concerted effort.

- It is recognised that various material cast specific properties and constants needed for CCG or CFG evaluation will be rarely available in real industrial situations. The variability in the materials data means that a deterministic approach may not be sufficient and that a probabilistic methodology and sensitivity analysis should be incorporated in the next version of the HIDA Procedure. The HIDA KBS is now available for iterative calculations and this can therefore be used for sensitivity analysis.

3.5 HIDA Data Bank

The Databank (DB) is based on Microsoft Access software. This DB exists as a shadow DB in the HIDA-KBS (Knowledge Based System) and can be used independently or as a part of the KBS - as explained in the next Section. The DB contains the HIDA experimental data (both lab and feature specimen tests), the HIDA Task 2 data – a large body of data collected from other projects worldwide, data and information on the industry plant cracking experience, and the HIDA material data and constants needed for the assessment of cracks. The DB operates through a purpose built user friendly interface.

3.6 Knowledge-Based System (KBS)

The **KBS Structure** forms the basis of the HIDA KBS. The general structure and the draft flow chart for the KBS is based on three 'Types' of analysis. The 'overview' stage of the KBS describes the overall objective of the KBS. In this analysis Type 1 is for component life assessment, Type 2 is to produce a design assessment for the components and the feature tests using postulated crack sizes, and Type 3 is for the interpretation of laboratory creep crack growth data. The KBS has been developed to deal with types 1 and 2, while for type 3 (data analysis) at present it uses the IC's Z-rate software available on the internet. It is planned that in the commercial version the Z-rate will be incorporated into the KBS software.

In the case of the KBS it is clear that through every stage additional layers are needed in which interactive decisions are taken to advance the problem through to completion. The different stages of analysis in the KBS cover the following;

Stage 1)	Input 1	Overview-Problem specification –Types: (1) design, (2) life assessment or (3) Data analysis
Stage 2)	Input 2	Material properties/Details from database or other sources- actual /mean/upper and lower bounds data.
Stage 3)	Input 3	Geometries: Laboratory tests/feature tests/components - Crack shape, size
Stage 4)	Input 4	System stresses/Loading/Loading history/residual stresses- actual /mean/upper and lower bounds data.
Stage 5)	Calculation	Values of $K/DK/J/\sigma_{ref}/C^*$ at different crack lengths – upper/lower bounds depending on the evaluation method
Stage 6)	Checks -	Static check for fast fracture and collapse
Stage 7)	Checks -	Ligament rupture creep analysis
Stage 8)	Analysis 1	Creep or creep/fatigue initiation
Stage 9)	Analysis 2	Fatigue crack growth
Stage 10)	Analysis 3	Creep crack growth
Stage 11)	Analysis 4	Creep/Fatigue interaction
Stage 12)	*Analysis 5*	*Sensitivity analysis/Comparisons/Repeat calculations*

In the final stage a comprehensive sensitivity analysis is proposed. This involves checking the sensitivity of the calculations to both variation in material laws and methods of calculating the relevant parameters.

It has been made clear from the review of existing defect assessment procedures and the HIDA data analysis performed on the laboratory and feature test specimens that detailed 'sensitivity' analysis is paramount in gaining increased confidence of the life assessment predictions.

4. Exploitation Plans and Follow-Up Actions

The exploitation Task on this project was initiated soon after the start of the project. The progress on this task has included dissemination of information to European organisations through technical newsletters and journals. A very successful international Mid-Term Conference was held on 15th, 16th and 17th April 1998 at CEA, Saclay, France. This was the first known major conference dedicated to cracking and associated failures in high temperature plant and has resulted in widespread dissemination of the structure, benefits and results of the HIDA project. The HIDA project benefited from the input of international experts who participated in the conference.

Some of the partners (ERA, Imperial College, and SPG) are now participating in a new VAMAS Standards Committee (TWA25) which has been formed to discuss the interpretation of data from component tests. Imperial College represented by Dr Kamran Nikbin chairs this committee.

The co-ordinator of the project Dr I A Shibli is now sitting on the newly formed CEN Committee Working Group (CEN/ TC121/ WG14) - formed to discuss the basis of a new European Standard on crack assessment.

An end of the project 'HIDA 2 Conference' is being held in October 2000 at MPA Stuttgart, Germany. The Conference is being organised by the European Technology Development Ltd and the eleven HIDA partners. The project findings will be discussed and disseminated in this International Conference.

The HIDA consortium has formed a post-project Interest Group to organise exploitation and dissemination of the project deliverables.

The HIDA Consortium has signed a Consortium Agreement for the exploitation (sale, maintenance etc.) of the project deliverables i.e. HIDA Databank and the HIDA KBS.

It is recognised that the present HIDA Procedure needs further validation on actual industrial components by systematic studying of their crack growth behaviour. It is also recognised that a comprehensive sensitivity analysis is required to study the effect of the variability in material properties and constants when assessing the crack behaviour of components where actual material data is not available (e.g. at the design stage or some life assessment situations). Further the lower and upper bounds of crack growth could be required for different safety margins in different safety assessment situations. To make the HIDA Procedure compatible with such demands and requirements the development and initiation of a new project is envisaged.

For information on any aspect of exploitation, interested parties can contact any of the Consortium partners shown above or the Co-ordinator at the following address: Dr I A Shibli, European Technology Development Ltd., 2 Warwick Gardens, Ashtead, Surrey, KT21 2HR, UK. **Tel:** +44 (0)1372 802555 **Fax:** +44 (0)1372.817.606 **E-mail:** ahmed@shibli.demon.co.uk

5. List of the HIDA Papers published.

A number of papers have been published as listed below.

Published in the HIDA Conference (April 1998, CEA, Saclay, France) Proceedings:

1. I.A. Shibli **-** Overview of the HIDA Project.

2. I.A. Shibli, B. Al-Abed and K. Nikbin **-** Scatter bands in creep and fatigue crack growth rates in high temperature plant materials data.

3. G. Fedeli, U. Gampe, K.Nikbin and I.A. Shibli **-** HIDA activity on 2¼Cr1Mo Steel.

4. V. Prunier, U. Gampe, K. Nikbin and I.A. Shibli **-** HIDA activity on P91 steel.

5. P.R McCarthy, I.A. Shibli and D. Raynor **-** A survey of European Creep Crack growth data generation from weldments and recommendations for a draft code of practice.

6. C. Poussard and D. Moulin **-** Creep fatigue crack growth in austenitic stainless steel centre cracked plates at 650°C. Part I: Experimental study and interpretation.

7. G. Fedeli **-** A survey of European industrial experience within the HIDA project.

8. C. Poussard, N. Celand, B. Drubay and D. Moulin **-** Creep**-**fatigue crack growth in austentic stainless steel centre cracked plates at 650°C. Part II: Defect assessment according to the A16 document.

9. G.A.Webster, K.M. Nikbin, M.R. Chorlton, N.J.C. Celard and M. Ober **-** A comparison of high temperature defect assessment methods.

10. A.S.Jovanovic and G. Wagemann **-** Knowledge-based system (KBS) for creep crack growth of high temperature components in HIDA Project.

Papers published elsewhere

11. Al-Abed B, Shibli I A, Le Mat-Hamata. – 'Creep and fatigue crack growth in high temperature materials', published in the Proceedings of the Conference on 'High Temperature Plant Integrity Issues', held at Cambridge University on 22 to 24 September, 1998.

12. K. Nikbin - Mechanical Engineering Dept, Imperial College, London, SW7 2BX - A unified approach to high temperature defect assessment methodology, paper presented at the Cape 99 Conference.

13. N.J. Celard, B. Pathiraj, K. Nikbin, G.A. Webster -
A comparison of residual stress measurements in steels using the X**-**ray and the Neutron diffraction techniques, presented in September 1999 at the CFEMS conference.

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