# The European Nuclear Fission Safety Networks' role in addressing reactor structural integrity

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## ABSTRACT

The European networks for structural integrity of nuclear plants were set up in the early 1990's to exploit the concept that the integrity of safety-critical components can be best-secured by grouping all the key players within dedicated networks, designed to integrate fragmented R&D work and promote harmonised practices. The European Commission's Joint Research Centre acts as Operating Agent, providing a neutral secretariat and co-ordinating the Reference Laboratory activities. The networks focus on three specific areas:

- Materials Ageing: AMES (Ageing of Materials Evaluation and Studies)
- Inspection: ENIQ (European Network for Inspection and Qualification)
- Structural Integrity: NESC (Network for Evaluation of Structural Components)

The paper summarises the most recent achievements of these groups, highlighting the crucial influence of networking, and explaining their strategy for supporting the continued safe and competitive operation of nuclear power plants.

## INTRODUCTION

The European Networks on materials ageing, AMES (Ageing of Materials Evaluation and Studies) inspection, ENIQ (European Network for Inspection and Qualification) were launched in 1992 and on structural integrity, NESC (Network for Evaluation of Structural Components) in 1993. They were identified by the European Commission's Joint Research Centre, after intensive negotiations with the European nuclear industry and its research base, as key areas where knowledge had to be rapidly accumulated to support the continued safe operation of reactors. The three Networks share common objectives, in particular to:

- integrate fragmented R & D work into clearly defined single projects involving all interested parties
- facilitate technology transfer and dissemination of information within and outside the Network
- establish the consensus to support harmonisation of procedures, practices and eventually standards

Also common is the Network structure in which the decision making is vested in a Steering Committee representing the key Network partners with an elected Chairman. The support to the Steering Committee and the organisation of the Network is the Operating Agent role taken on by the European Commission's Joint Research Centre who is also responsible for the establishment of a Network Reference Laboratory which is centred on the JRC but which comprises all key laboratories of excellence of the partners.

Each Network has evolved from the basic prescription in its own unique way nevertheless the *modus operandi* are essentially the same. All the Networks run projects and actions initiated within the Network and supported by the partners through so called "in-kind" contributions. Equally all the Networks are associated with projects which are funded (partly) from external bodies including in particular the Shared Cost Actions (SCA's) of the European Commission's Research Framework Programmes. In many cases these small dedicated SCA research projects are utilised by the Networks as pilot or seed projects for subsequent larger Network supported actions. In other cases they are used to exploit further the results of major Network projects which are ostensibly completed but where some important open questions remain. An example is shown in Figure 1, in this case for the NESC project. This strategy is common to all the Networks but each has its own particular ratio of Network supported and externally funded projects.

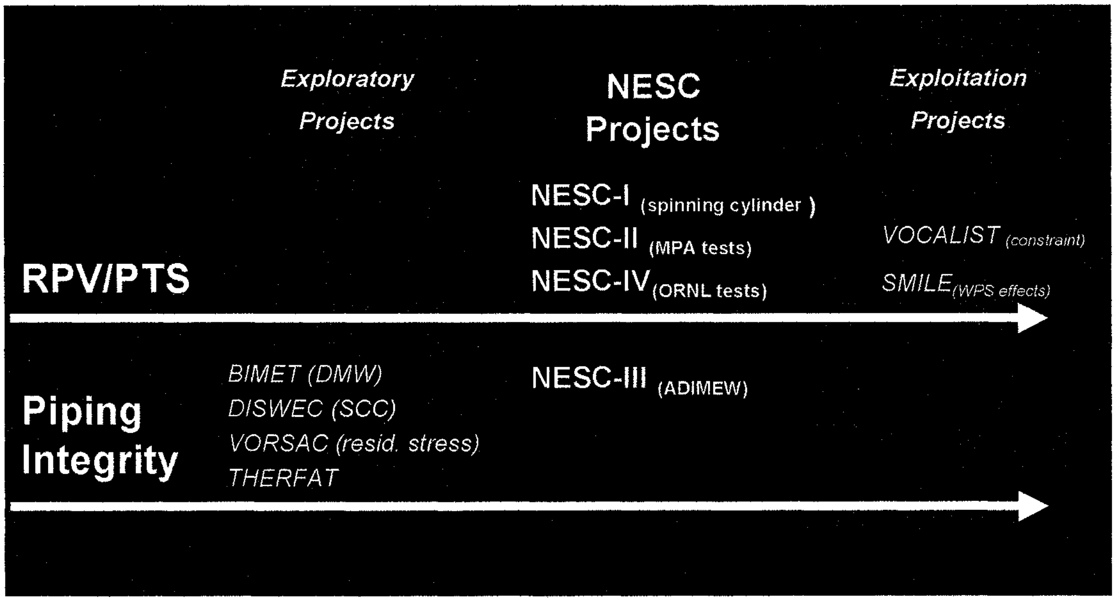


Figure 1. Development strategy for the NESC Network projects

Another crucial aspect relating to the evolution strategy of the Networks, concerns membership. From the outset the Networks were considered to be essentially European based, although a special exception was made for the NESC Network to include American participation because of the high level anticipated and because of the traditional strong links between the European nuclear industry and research laboratories in the area of plant component structural integrity. In the last years the Networks have anticipated political change within Europe and commenced to draw participation from those Eastern European states who are considered as applicants for European Union membership in the near future. Although this action is clearly limited to those countries with a nuclear industry, all of the Networks now have active participation from partners in the Czech Republic and Hungary and new members from Slovakia and Bulgaria are at different stages of involvement in each Network. In an interesting recent development, the NESC III Project related to the behaviour of bi-metallic welded components has attracted interest also from the non-nuclear industry with the participation of Poland.

The purpose of the present paper is to update the structural mechanics community as to the main progress within the Networks while stressing the importance of the networking approach which has enabled a rapid evolution towards an established and accepted status for the Networks in the international nuclear safety arena.

**AMES**

The AMES (Ageing Materials Evaluation and Studies) Network forms the framework for a range of nuclear safety driven activities aimed to understand, monitor, predict and mitigate the degradation of critical materials in view of plant life management of primary component of nuclear reactors. Western and Eastern European types of steels are involved in the various actions undertaken as international co-operation projects with key players in the European Union, CEEC (e.g. Czech Republic, Hungary) and NIS (e.g. Russia, Ukraine) countries. The AMES network was set up to bring together the organizations in Europe having the greatest expertise on nuclear reactor materials assessment and research, with the following objectives to:

- Provide information and understanding on neutron irradiation effects in reactor materials in support of designers, operators, regulators and researchers
- Promote the integration of national into international programmes
- Establish and execute AMES projects on key subject areas
- Act as a European Reference and Review Group
- Offer technical support to policy making and regulatory bodies
- Impart a basis for development of common European standards
- Participate in collaborative programs with the New Independent States (NIS) and the Central and East European Countries (CEEC)

The application of drivers to the strategic policy of AMES is detailed in another paper at this conference [1], but the overall groupings of all the actions have been recently distributed among seven so-called Task Groups, two strategic and five technical-scientific, which will have the goal of carrying on focussed in-kind studies on open issues. The new AMES Task Groups are the following:

- Linking National and AMES strategies
- Linking AMES Strategy with Eastern Europe (EPLAF)
- Master Curve implementation for fracture toughness assessment
- Annealing and re-embrittlement issues
- Radiation embrittlement understanding
- Ageing mechanisms: influence and synergism
- Watch-and-alert on open issues (IASCC, NDT, …)

In some of these Task Groups, the elaboration of existing data and dedicated meetings of experts sent by the AMES partner organisations and integrated with open workshops, will allow a broad state-of-the-art review of subjects not yet dealt with, i.e. re-embrittlement, IASCC, and the definition of further experimental campaigns. Previously most of the activities were dedicated to the pressure vessel of nuclear power plant, which is certainly the critical non-replaceable component in view of safety and plant end-of-life. Recently, more and more issues related to reactor internals are surfacing, in particular the issue of IASCC (Irradiation Assisted Stress Corrosion Cracking). For all Task Groups both in kind contribution and externally funded projects are being integrated to provide final deliverables of the Task Groups.

The Operating Agent for the Network is responsible for the organisation of the realm of activities going on within the Task Groups but also coordinates the Reference laboratory facilities especially the LYRA facility (Figure 2) of the HFR (High Flux Reactor) for exposing materials to controlled irradiation and ductility and fracture toughness rigs for both irradiated and un-irradiated test-pieces.

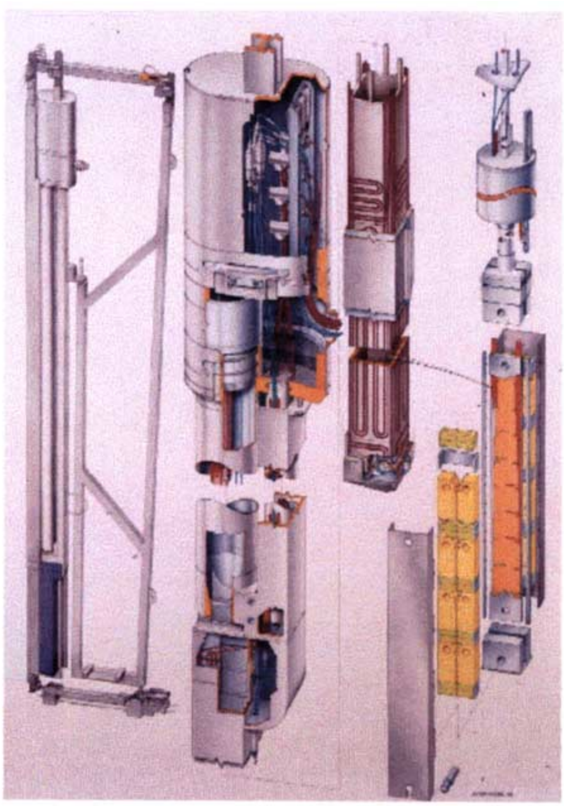

Figure 2 The LYRA facility for exposure of materials to irradiation in the HFR reactor

Great importance is also attached to the dissemination activities in particular the preparation of a large number of reports and the operation of a continuously updated web site (www.jrc.nl/ames/) These actions are crucial to prevent isolation of the Network from the many other recognised reactor ageing programmes going on through out the world such as those operated under the auspices of IAEA, OECD and TACIS-PHARE.

AMES is unique amongst the Networks in relying on a high proportion of externally funded SCA projects both in the exploratory/seed role but also exploiting earlier work. This approach started already in the 4th Euratom Framework Programme with the successful projects SINTER, INTACT, MADAM, REFEREE, AMES NDT, AMES DOSIMETRY and RESQUE covering state of the art reviews, experimental projects on damage, fracture toughness and NDE, harmonisation of practices and validation methodologies. Numerous projects have been launched in the 5th Framework Programme studying subjects as diverse as phosphorus influence on RPV steel irradiation embrittlement to development of LWR reference electrodes, from fracture mechanics based trend curves to temperature based VVER surveillance programmes. A full update including very recently approved projects will be given in the AMES presentation at this conference.

**ENIQ**

The general objective of the European Network for Inspection and Qualification (ENIQ) Network is to co-ordinate and to manage expertise and resources for the assessment and qualification of Non Destructive Testing (NDT) systems, primarily for nuclear components, at European level. Additionally, ENIQ works towards a harmonisation of codes and standards in the field of Inspection Qualification and Risk-informed In-service Inspection.

ENIQ was founded in 1992 recognising the need that the issue of inspection qualification requires important resources. In March 1995 the Steering Committee of ENIQ approved the first issue of the European Methodology setting out general guidelines on how to conduct and organise inspection qualification exercises. In 1997 a second issue of the European Methodology was published and, meanwhile, a pilot study was launched in order to investigate its feasibility in practice. The pilot study underpinned the European Methodology's suitability to develop detailed qualification schemes for particular components. As a consequence, many countries have implemented the general principles of the methodology in their national qualification programmes. At present ENIQ groups more than 50 organisations (power plant operators, inspection service vendors, manufacturers and research institutes) from 9 member states of the European Union (EU), Switzerland, Hungary, Slovakia, Czech Republic, and Bulgaria. The latter has recently joined the network as observer.

The main objectives of ENIQ are as follows:

- To co-ordinate expertise and resources for the assessment and qualification of NDT systems, primarily for nuclear components, at European level
- To develop qualification schemes, both general and specific to components
- To work towards a harmonisation of codes and standards at European level in the field of inspection qualification
- To set up a co-ordinated approach for in-service inspection qualification in view of establishing an industrial co-operation between the EU and CEEC, Russia and Ukraine
- To study risk-informed inspection concepts and possible consequences for inspection qualification

Although much work is to be done in exploiting the potential of the European Methodology (such as in a 2nd Pilot Study) ENIQ has recently launched a discussion to widen the objectives of the network into other areas of inspection reliability and risk-informed decision-making, e.g. maintenance and instrumentation. The technical work within ENIQ is carried out by a series of Task Groups, each reporting to the Steering Committee:

TG1: Gathering of information
TG2: Development of qualification schemes
TG3: Application and implementation of qualification schemes
TG4: Risk-Informed In-service Inspection

In TG1, as a Network supported action, the Steering Committee of ENIQ decided to set up a database of qualification test pieces that can be made available within the network. A questionnaire has been drafted and approved by the Steering Committee and is circulated at present amongst the network members to collect the data. A strong link has been set up with VVER owners in order to make a common database with the support of IAEA. An externally funded (SCA) project (SPIQNAR) on a study of the benefit and eventual acceptance of synthetic defects replicating real defects in qualification was accepted in the Nuclear Fission Safety Call of the 5th Framework Programme of the European Commission and this commenced in October 2000.

In TG2, the first pilot study had underpinned the European Methodology's suitability to develop detailed qualification schemes for particular components. Nevertheless, it was concluded that further work was needed to explore how to fully exploit the potential of Technical Justifications in the qualification of inspection procedures, using theoretical modelling and parametric studies, thereby reducing the number of test piece trials on full-scale components. It was therefore decided to conduct a second pilot study based on an approved Method of Working document which sets out the general objectives of the second pilot study, describes its different phases, and details the implementation steps required. The pilot study will focus on surface cracks, near surface cracks, and side-wall lack of fusion defects in Boiling Water Reactor (BWR) components comprising the nozzle to shell weld section. Both existing and new BWR components will be utilised. At present a new component, ENIQ Nozzle Assembly 1, is being manufactured under the control of the ENIQ Reference Laboratory as shown in Figure 3. The first set of inspections, a parametric study on the ENIQ Nozzle Assembly material and the elaboration of a Technical Justification are planned for 2001.

Figure 3: ENIQ Nozzle Assembly 1

In TG3, the Network has commenced a survey amongst its members and regulators regarding the feasibility of a European recognition scheme for inspection qualification. In addition, The EC's DG JRC and DG TREN have published a report on the strategy of future training related activities in the CEEC, Russia and Ukraine in the frame of European Nuclear Training Forum (ENTF). The strategy focuses on the measures required to ensure the operation of an efficient national training system.

Finally the TG4 has recently been reactivated after a quite long standstill period, as a result of the results from a seed type, externally funded SCA concerted action, European Network of Risk-informed In-service Inspection (EURIS). The group confirmed its main objective of developing a methodology appropriate to the European Plant Operators needs using the concept of risk and harmonising the different EU initiatives on this subject. This methodology should provide a framework for the European Plant Operators to develop a risk-informed management strategy to optimise the plant inspection. As a consequence, Task Group 4 has produced a discussion document on risk-informed in-service inspection, based on the material produced by EURIS. This document represents a first attempt toward the European methodology and contains all the main elements of the risk-informed decision making process to be used for the development of an inspection plan. The integration of these elements to form a single framework that encompasses plant inspection to ensure a cost effective process of optimising the plant risk, will be the objective for a further document. A study on the link between in-service inspection sizes selected using risk based methods and those from inspection qualification is in hand and a new activity to study the use of structural reliability models in risk informed decision making processes is about to be launched as a SCA project with the name NURBIM.

With regard to the activities of the Operating Agent, a new ENIQ web site (www.jrc.nl/eniq/) has been created in order to facilitate the communication between the ENIQ members by permitting online access to important documents (e.g. minutes, discussion documents, etc.), and to improve the information dissemination process for both within the network and for external publicity in particular to reinforce the adoption of the European Methodology. The ENIQ Reference Laboratory has enhanced its capability for the insertion of artificial defects with the installation of a spark erosion machine dedicated for large components and used for the 2nd pilot study. In addition plans are in hand for installing a new linear accelerator X-ray machine to replace an existing unit which can no longer offer adequate focusing performance and reliability; this is essential to maintaining the Reference Laboratory's capability to inspect thick-walled components along with an ultrasonic phased array unit as such systems are becoming increasingly used in cases where variable focus depths and angles can enhance performance.

**NESC**

The Network for Evaluation of Structural Components (NESC) promotes better integration of multi-disciplinary structural assessment procedures used to assure the continued safe and efficient operation of European nuclear power plant. NESC brings together some 60 operators, manufacturers, regulators, service companies and R&D organisations to perform large-scale experimental projects. The overall aims of NESC are to:

- undertake collaborative projects capable of validating the entire structural integrity process.
- work towards best practice and the harmonisation of international standards.
- improve codes and standards for structural integrity assessment and to transfer the technology to industrial applications

NESC was set up in 1993 to address these issues with JRC-IAM as independent operating agent. The network projects are designed to combine all aspects of structural integrity assessment including inspection, materials characterisation, fracture mechanics and instrumentation. Figure 1 shows an overview of current activities, which are focused in two technical areas related to the structural integrity of light water reactors, the reactor pressure vessel and primary circuit piping. Four full "NESC" projects are currently running, together with exploratory/seed studies aimed at stimulating future projects or follow-up activities to support the exploitation process. As with all the other Networks, dissemination plays a major role in NESC and a dedicated website has been set up for internal and external access (nesc.jrc.nl)

NESC-I, which completed its post-test evaluation phase in 2000, has already provided crucial insights into the behaviour of light water reactor vessels under pressurised thermal shock conditions. Over the last couple of years, three new projects have been accepted in the network structure. NESC-II and NESC-IV are both concerned with the assessment of shallow defects, which typically dominate the assumed defect density distributions in structural integrity assessments. NESC-III focuses on the testing of a full-scale dissimilar weld assembly representative of a critical primary circuit component.

As far as NESC-I is concerned, by the year 2000 the assessment of the seven-year NESC-I project was completed. This was the first large-scale project to evaluate the reliability of the entire process of structural integrity assessment and concentrated on the consequences of Pressurized Thermal Shock in a reactor pressure vessel containing implanted defects. It examined all the key components including defect inspection accuracy and reliability, material property data requirements, test measurement techniques, and the appropriate levels of complexity for thermal/structural analysis and fracture assessments The results were presented at the highly successful seminar "Structural Integrity Assessment – How Safe is It?" held in March 2000 in Paris and are now summarised in series of 19 Evaluation Reports and an Overview Report (Table 1). All were subject to internal peer review within the network task groups and given final Steering Committee approval.

| Report | Contents |
| --- | --- |
| TG1 Inspection | summary & analysis of the pre- and post test inspection trials |
| TG2: Materials Characterisation | summary of the materials characterisation work on the NESC-I cylinder material |
| TG3: Structural Analysis | summary of the pre- and post-test stress and fracture analyses |
| TG4: Instrumentation | Selection and performance of the instrumentation used in the NESC-I spinning cylinder test |
| Destructive Examination Advisory Group | Assessment of the defect present in the cylinder and post-test analysis of crack growth |
| Constraint: | considers the initiation and growth of significant defects through the application and comparison of constraint-based methodologies. |
| Cladding: | summarises cladding induced factors that influence the initiation and extension of through and sub clad flaws. |
| Sensitivity Analysis: | assessment of the sensitivity of the integrated process to NDE, materials, and structural analysis variability |
| Crack Arrest: | the design of the test to produce crack propagation has also allowed verification of crack arrest methods based on specimen test data. |
| Residual Stresses: | measurements were conducted both before and after the test; the usefulness of this data in the structural integrity assessment is evaluated. |
| Probabilistic approaches: | potential for evaluation of variability in flaw sizing, fracture properties, crack driving force parameter is summarised |
| Consistency in Fracture Assessment. Criteria: | considers the transferability of different fracture toughness parameters in analysing the observed crack propagation. |
| Relevance for Reactor Transient: | comparison of test crack driving force history with typical reactor transients. |
| Codes & Standards: | a comparison of various national codes and standards applied in the Test inspection and analysis, commenting on the adequacy of current safety margins |
| Relation to other Large Scale Projects: | comparison of NESC results to other PTS experiments, such as those previously analysed in FALSIRE. |
| Technology Transfer to other Nuclear & Non Nuclear Plant: | evaluates the potential for transfer and exploitation of the NESC results to other fields. |
| Lessons from Networking: | Pro's and con's of international networking as a route for improving integrated structural assessment methods. |
| Final NESC 1 Overview Report | an overview of the NESC results |

Table 1 – The NESC-I Project Reports

After the successful execution of the two large-scale PTS tests at MPA Stuttgart for the NESC-II project in 1999, the materials characterisation and structural analysis groups have performed extensive post-test analyses. The network also launched two new projects at the end of year 2000 with the first of these, NESC-III, looking at a large-scale test to be performed at EDF on a dissimilar weld assembly of aged PWR Class 1 piping in 2002. For this project the crucial funding of the component tests including construction of the test assemblies and some limited materials testing, residual stress measurement and test design analysis is part financed through the ADIMEW SCA whereas the total project is extended substantially through Network support. Focus is currently directed towards the production of full-scale dissimilar weld test assemblies, in particular for the structural test, for materials characterisation work, for residual stress analysis and also for the planned inspection round robin. In view of recently discovered cracks in dissimilar metal welds for example those related to debonding at the buttering/ferritic interface and to inter-dendritic stress corrosion cracking the inspection trial is extremely timely. This inspection exercise on defects in a dissimilar metal weld is expected to be the first of its kind involving different organisations in many countries. NESC-IV will involve a special test series on defect-containing beams conducted at Oak Ridge National Laboratories in the Clad Cruciform Testing Program (Figure 4a and 4b). The tests are designed to clarify the role of biaxial stress effects on shallow surface and embedded flaws in the low temperature transition region. Through the Network additional tests have been introduced which will serve as benchmarks for the VOCALIST externally funded programme which has been launched to exploit the importance of constraint as shown through the NESC-I Spinning Cylinder test. As these benchmark tests will be carried out in early autumn 2001, pre-test structural mechanics analyses and material characterisation work is already under way.

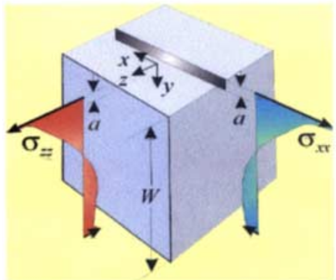


Figure 4a Biaxial Stress State in RPV

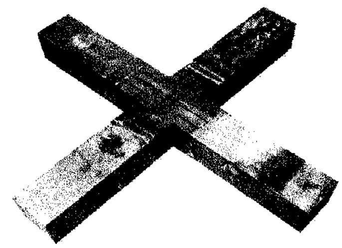

Figure 4b ORNL Cruciform Specimen

In the last months a new activity has been accepted for external sponsorship as the precursor for a NESC-V project on thermal fatigue evaluation of piping system tee-connections. The initial programme will assess field data related to the hot/cold fluid mixing problem at tees (Figure 5), attempt to model the problem from a thermo-hydraulic viewpoint and verify using specially designed benchmark testing. NESC-V is expected to use this project as an input towards a European Methodology for Thermal Fatigue Assessment.

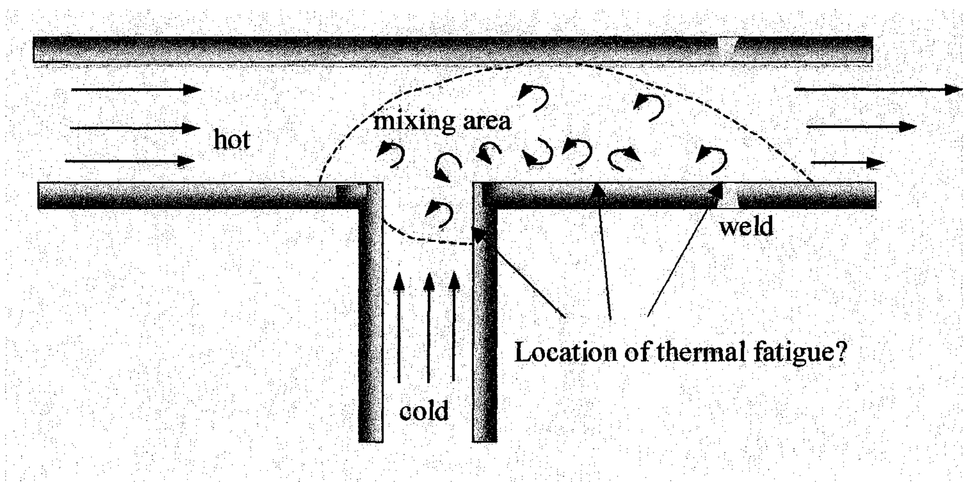


Figure 5 Cause of thermal fatigue at a piping tee-connection

## CONCLUSIONS

In less than 10 years the European Networks related to reactor safety, AMES, ENIQ and NESC have firmly established themselves in the nuclear fraternity. The networking of all the key players in the field in particular from Europe and the Eastern European countries has led to considerable benefits for all involved. The partners' contributions to the Networks, either "in kind" or partly externally financed, have been remarkable and the results and deliverables from the Networks lend testimony to the synergies achieved. The combination of cuts in research budgets with a willingness to globalise from all countries leaves no doubt that international networking is the best, if not the only, way left to achieve a safe and competitive nuclear industry for years to come.


## ACKNOWLEDGEMENTS

The authors greatly acknowledge the contributions from all the Network partners and their organisations.