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FROM PISC TO RISK INFORMED INSPECTION

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ABSTRACT

In this paper the correlation between inspection effectiveness, inspection qualification and risk informed inspection will be treated in view of harmonisation of inspection of nuclear plant components. Through the different phases of the PISC programme the necessity has been demonstrated to show the effectiveness of the inspection through a formal process of qualification in order to ensure that a certain level of effectiveness has been reached. Inspection qualification is indeed the way to quantify the capability level of inspection techniques used. The targets to be met by the inspection is information which should be obtained from risk based analyses.

1. INTRODUCTION

1.1. Rigidity and shortcomings of prescriptive inspection codes

Since the early sixties, inspection of structural components is harmonized through prescriptive codes and standards. An important example is the case of the in service inspection (ISI) codes for nuclear reactor components such as the ASME code, the KTA rules and the RSEM code, etc. It could be claimed by ASME that harmonization of ISI was reached in many countries of the world through the application of Section XI of the American code. Section XI is indeed used in the USA, Canada, Japan and in some European countries either as a strict requirement or as a basis for basic inspection activities to which specific national requirements are added. In several other European countries other (national) codes are used, sometimes in replacement of the ASME code.

Until very recently all these different codes prescribed in detail the procedures and NDE techniques to be used. It followed that it was difficult to replace existing NDT procedures/techniques by more performant ones which were either superior from a technical point or allowed a reduction of the inspection effort. This due to the fact that one had to show the equivalence or superiority of the newly proposed inspection procedure/technique to the satisfaction of the regulatory body. This impedes a real competition between service vendors proposing standard procedures and those proposing new technologies.

Vendors are obliged to use the national standards of the different countries. Both from a safety and economical point of view this leads to the negative situation, where the service vendor can not use its best competencies or techniques.

Furthermore these prescriptive codes are sensibly different one from the other for very similar situations. This adds to the difficulty to open the important market of in-service inspection.

For each of these codes taken separately and also for in the current industrial practice propose very different techniques for different situations are proposed, for example: X-rays for fabrication inspections, and ultrasonics for in-service inspection. Such differences may be justified by the particular environment in which these inspections are conducted or by the type of defects to be detected or evaluated. However, what is done for in service inspection is often also applicable to other situations and it is often more by tradition that certain techniques are used in specific situations. Several programmes were conducted to show the inter-change of procedures more based upon ultrasonics with those based more on X-rays.

Exercises such as the Programme for the Inspection of Steel Components (PISC) [1] demonstrated that inspections conducted along ASME Section XI (editions anterior to 1989 and in particular the editions anterior to 1986) were subject to insufficient effectiveness in several situations. Even the 1986 edition of this Section XI, issued on the basis of PISC II results, appears, in PISC III, to lead to some failures in detection of relevant flaws and in sizing of defects.

1.2. Evolution towards inspection codes based on performance standards

On the basis of the technical conclusions resulting from international co-operation and consensus, code and standard bodies involved in exercises such as PISC as well as plant operators, service vendors, regulators and R&D institutions started very soon to consider the demonstration of capability of inspection techniques on mock-ups as the ones used for the round robin tests of PISC.

The idea of demonstration of effective performance came to the fore early : in 1975 in the ASME NDE Task Group; in 1979 in the PISC I group ; in the early 80s in UK as a result of PISC and DDT (Defect Detection Trials) and in view of the public inquiry for Sizewell B.
The IVC was created at Risley (AEA Technology) in 1982. A programme on NDE performance demonstration was accepted by ASME Section XI in 1987 and the Appendix VIII of Section XI was issued in 1989/1990 [2-3].

Starting in 1990/91 several European countries began to develop programs or reflection groups on NDE performance demonstration. Already in 1987, JRC, operating agent of PISC proposed to embark in a programme called EBIV (European Bureau of Inspection Validation) which was officially created as European network in 1992 and renamed ENIQ (European Network for Inspection Qualification) in 1993. Performance demonstration was then called qualification in the European Union and Switzerland [4]. ENIQ issued the first edition of the European Methodology for Inspection Qualification in 1995 [5]. Nuclear Regulatory Authorities in the European Union and Switzerland created a task force on NDE qualification in 1993 to express their common position on inspection qualification in 1996 [6].

The development of the PDI programme by EPRI in the USA is based on the ASME Section XI Appendix VIII but the implementation of the programme indicates that the principle of technical justification, considered essential in the EU by the licensees and the regulators, is also considered, as a minimum as a premise to the development of the performance demonstration trials.

Sweden and France have now national codes involving ISI qualified along performance demonstration schemes based on the ENIQ methodology [7-8]. Other countries are following ASME/EPRI-PDI or develop qualification along ENIQ principles depending on the cases of application and of the opportunities [9].
Eastern European countries are also following the evolution with a particular rapidity shown by the Czech Republic helped by the PHARE programme : qualification is being developed for the ISI of pressure vessels, for the inspection of primary piping and for the steam generator collector inspection [10]. The IAEA of Vienna will issue guidelines for inspection qualification for VVER operating countries which are in good agreement with the ENIQ principles [11].

In 1997 it appears clearly that most industries and service companies in the EU move in the direction of qualification to be based on the major elements of the European Methodology established by ENIQ, but with different emphasis on each of these elements as a function of historical development, national traditions, legal particularities. Also in the USA there seems to be a move in this direction [12].

Qualification of inspection procedures for well known components of the nuclear reactor is effectively a way of harmonizing inspection requirements with the objective of being equally open to any inspection technology

1.3. Target to be reached by NDE procedures to be quantified through inspection qualification

A qualification procedure for an inspection is based on precise inspection objectives or targets to be defined prior to start the qualification.
The objective of qualification is therefore to set the level of effectiveness of the inspection. It should ensure the same (minimum) level of effectiveness of different inspection procedures proposed, if successfully qualified.

Qualification is thus the key to the introduction of performant inspection techniques, of new technologies in view of increased effectiveness and economy (inspection effort reduction), of elimination of non performant procedures and techniques, of replacement of a particular technique by another (e.g. RT by UT or ET) or by a combination of techniques that would combine effectiveness in various situations, of high performance for defects of real concern and of economy (speed of execution, remote control, no irradiation of operators, etc.)

1.4. NDE targets to be fixed by Risk Informed Assessments

Targets for NDE based inspection procedures must be precise. They are the basis for the qualification that will be imposed to the inspection system. Such targets must result from the effective needs to be defined by the plant operator. The management of the plant with an optimum maintenance programme will tend to apply principles of "availability guided maintenance" in opposition to the one of "inspection guided" which programmes the plant shut downs instead of taking simply benefit of opportunities for inspection. Such principles are the ones of risk based management. It is logical to expect that the inspection targets will result of risk based assessments.

2. OVERVIEW OF PISC RESULTS

Until 20 years ago there was little quantitative information on the effectiveness of NDT techniques especially when they were applied to such components as those built into the main pressurised coolant circuits of nuclear power reactors. Because this information is vital to the assessment of the integrity of such plant a co-operative international programme aimed at providing it was started in 1974 under the joint auspices of OECD/NEA and EC/JRC which became known as PISC (Programme for the Inspection of Steel Components [1]). Throughout its studies this programme had made use of test assemblies that were realistic in size and materials, into which were deliberately introduced realistic and artificial flaws and defects. These assemblies were examined by well-defined techniques applied by people who knew about such examinations; often these people came from teams actually involved in such work on real structures; for example those doing in-service inspections (ISI) of nuclear reactor pressure circuits. In each of the PISC Round Robin Tests (RRT) the results obtained by each team of examiners were reported to a independent laboratory, that of the EC Joint Research Centre playing the role of operating agent of the programme, using reporting procedures that were carefully prescribed. On completion, the numbers, sizes and location of the flaw indications given in the various reports were compared with the actual size and location of the flaws as revealed by the results of special validation tests often involving partial or complete destructive examination of the regions surrounding such indications. Because the general interest seemed to concentrate first on gaining more information on the effectiveness of ultrasonic examination techniques (UT) the PISC work has concentrated on studying these techniques effectively applied for ISI.

The first part of this programme, PISC I [1], tested thick weldments typical of nuclear pressure vessels and showed shortcomings in some common industrial NDE procedures representative of those used under the rules of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code section XI (ASME XI) as issued in 1974/77. This led to a second and larger part of the PISC programme (PISC II) involving parametric studies and a series of RRT's on a range of typical recent welded plate materials and nozzle/plate assemblies. Parametric studies conducted on well designed simple steel blocks were of great value in validating and elaborating the conclusions arising from the RRT's. They covered such topics as the effect of equipment variables, the effect of cladding characteristics, the effect of defect variables and the potential of advanced UT probes. These parametric studies were of particular value in helping the validation of mathematical models in the PISC III programme. Taken overall the results of all the PISC II tests showed that improvements in the effectiveness of NDE could be achieved by use of additional techniques to those used in PISC I and particularly it was of value to add techniques which were optimised to deal with the type of defects to be detected in pressure vessel component : e.g. near surface and surface defects. Another important conclusion was that for NDE effectiveness one should turn to the use of higher sensitivities and lower reporting ("cut-off") levels than those used in ASME XI 1974/77 and PISC I.

In the light of these results and other evidence, already in 1982 and 1983, positions were taken by the CEGB for the Sizewell B public inquiry, ideas were more precisely developed for the setting up of the Inspection Validation Centre (IVC) [2]. ASME XI was deeply modified in 1986 [3]. Several national institutions used the PISC II results to improve the ISI practice.

Detailed technical results and associated discussions brought about the awareness that an improvement in inspection reliability could be stimulated by a change from the "prescriptive" approach of the earlier standards to the codified use of inspection qualification.

These developments encouraged a continued interest in the type of work that had been done in PISC I and II so that by 1986 there was considerable international enthusiasm for a third part (PISC III) aimed at validating the PISC II work on pressure vessel weldments under even more realistic conditions and also in extending the PISC type approach to the testing of other important components of the primary circuit of nuclear reactors. The resulting PISC III programme involved eight very different Actions [14]. The differences in nature and aims, the differences in materials and geometry tested, the differences in technique, in time scale and in appraisal criteria make these actions each a somewhat separate programme shown in Figure 1. The EC Joint Research Centre, Institute for Advanced Materials Ispra and Petten, provided PISC III with its Reference Laboratory and Referee Group and acted as Operating Agent. This with the associated work and several test assemblies represented a major contribution from the EC to be added to the contribution from other participants, combining in total some 30 million ECU's "invested" mainly by the nuclear industry in 6 years.

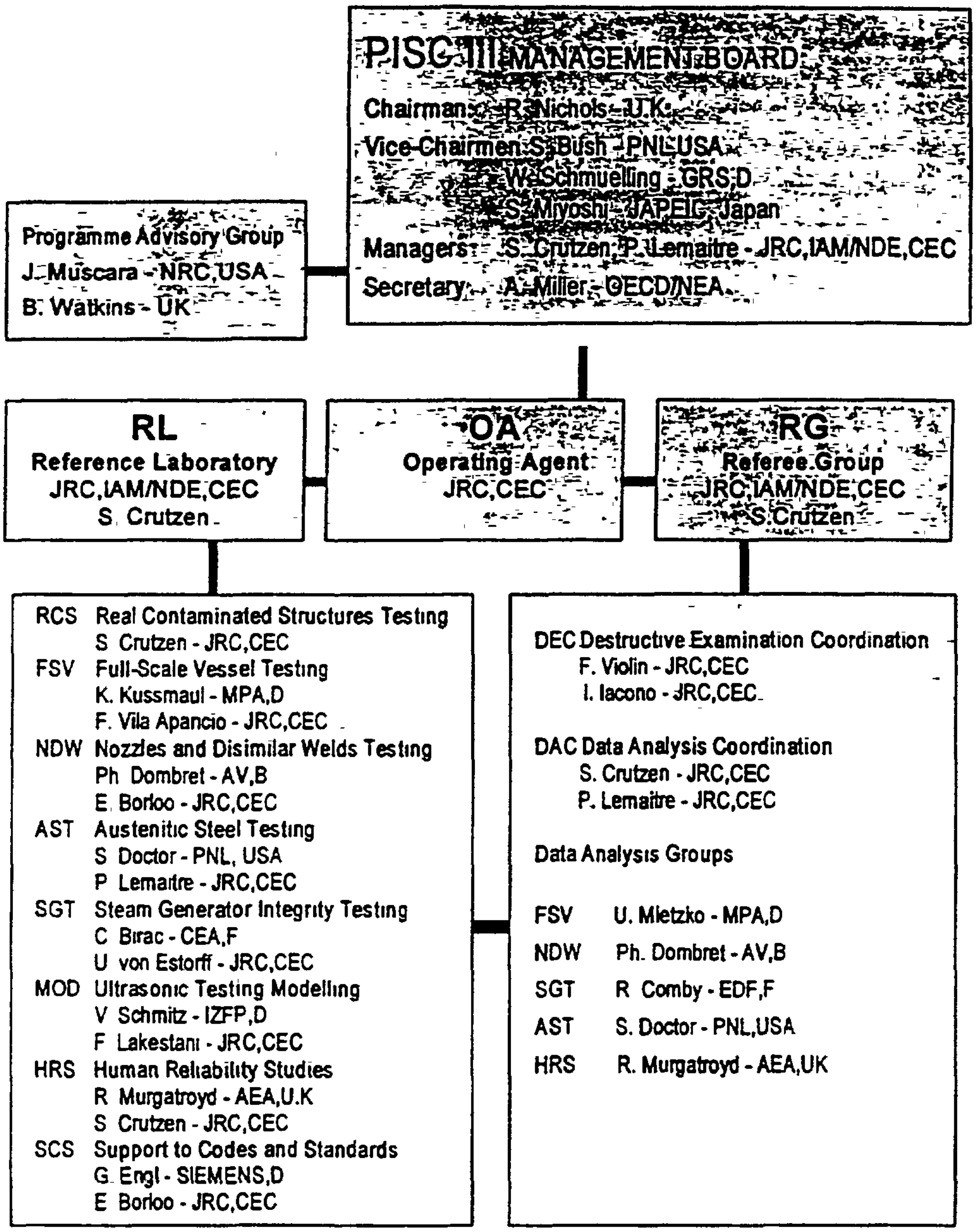

Figure 1: Organisation of the PISC III Programme

The first major achievement of PISC III has been to show that a complex co-operative international research activity covering numerous and differing actions can be completed with good will and can arrive at meaningful conclusions which are a consensus of the views of the participating organisations.

Turning to some technical conclusions, PISC III has confirmed in its various RRT's on different materials and geometry that the most effective ("safest") UT inspections are those specific to the situation and carried out with high sensitivities and low reporting "cut-off" limits when this is acceptable to the material. An example of a result obtained in the framework of PISC Action 4 on austenitic steel testing [15] is given in Figure 2. It is also desirable to use procedures which involve multiple and diverse techniques provided that these are chosen on the basis of well established principles of physics and that one takes into account the size, location and types of flaws which have to be found. Mathematical modelling can be helpful in this selection. Human factors can be very important if for example quality assurance programmes are absent.

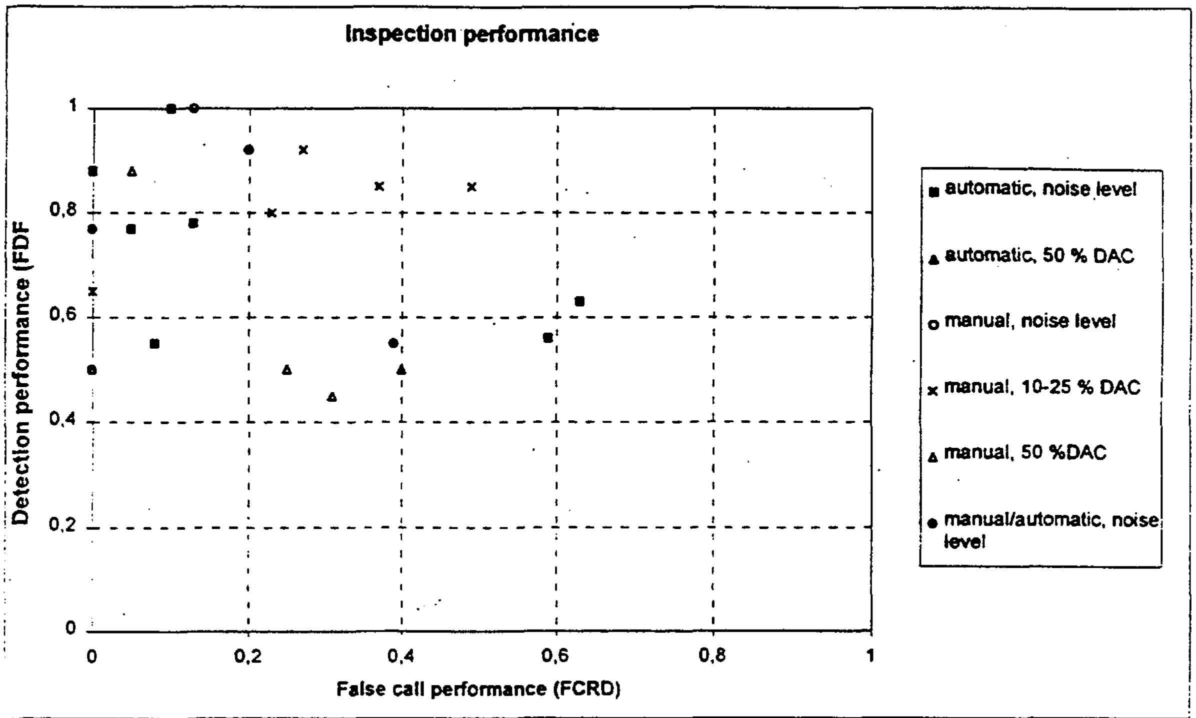

Figure 2: Example of typical results of inspection effectiveness obtained in the framework of PISC III Action 4 on wrought-to-wrought pipe welds.

3. ENIQ

From the PISC result and know-how generated by the execution of the various RRT's and parametric studies, it appears that the final decision on whether a particular team can provide an adequate level of NDE effectiveness requires them not only to employ appropriately trained, experience, qualified and certified personnel using well chosen techniques and using well defined procedures for interpreting data; but also requires them to satisfactorily carry out formally conducted trials on realistic flaws in realistic geometry test assemblies: qualification tests as already stated at the end of PISC II (7).

Having provided evidence on the importance of human factors to NDE effectiveness the PISC III work has thus stressed the contribution that can be made by inspection qualification. It has also indicated many of the key features, such as specimen design and manufacture, defects fabrication and implant and the conditions and nature of the tests for such approaches to be most effective. It has shown how mathematical models relating to NDE/flaw interaction can be validated and stressed the importance of such models for optimising NDE procedures.
PISC has also given clear ideas on targets that can be proposed for inspection qualification in detection and sizing.

A seminar on Inspection Qualification held in October 1992 at Ispra discussed the results of PISC III Action 8. This seminar was very fruitful in terms of the generation of the first common basis for a European Methodology for Inspection Qualification, included in the programme of the European Bureau of Inspection Validation (EBIV), created in 1992 and renamed in 1993 as European Network for Inspection Qualification (ENIQ). JRC Petten is playing the role of Operating Agent and Reference Laboratory for ENIQ. [4].

The main principles of inspection qualification as described in the European methodology are based upon practical test piece trials and technical justification (TJ) of the capability of the inspection procedure [5].

The need for a TJ comes from the impossibility to demonstrate rigorously the capability of NDT procedures if relying only on few (e.g. 30) defects in blind test pieces:. In order to assure that good results for detection and sizing are not obtained by chance asks requires the explanation/demonstration of capability. This demonstration is based on all information available, on physical reasoning and on the analysis of the system to identify essential parameters, to be assembled in a technical justification. Further demonstration of capability and understanding is often made on test pieces, designed as a result of the TJ and used for open trials: The techniques used are tested to verify their capability for limit cases defined by the essential parameter analysis. The TJ is an essential concept of the European Methodology for inspection qualification.

The practical tests on realistic assemblies can be blind or open ones in view of the demonstration of the capabilities of the NDE techniques used in the procedure. Such tests require validated assemblies, simple blocks, validated defects in these assemblies to satisfy the simulation of inspection situations representing a good sampling of all the cases to be considered.

A qualification dossier has to assembled containing all the information generated by the qualification process:

- input information, to be provided prior to the start of inspection qualification:
    * details of component(s) to be inspected
    * defect situation and details of the defects to be detected and/or sized
    * in-service inspection performance to be achieved
    * full details on the inspection system to be used (inspection procedure, equipment and personnel
- qualification procedure (conduct of qualification):
    * objectives of the inspection qualification
    * qualification rigour/level
    * technical justification
    * way the technical justification and NDT procedure will be assessed
    * details on how the practical trials will be conducted (blind and open)
    * way the results of the qualification will be evaluated
- conclusion(s) of the qualification
    * results of all assessments and practical trials, including range of essential variables for which the qualification is valid
- if necessary, updating of the qualification dossier, taking into account feedback from site experience

Within ENIQ a pilot study [15] is executed to demonstrate the use of the proposed methodology and to generate recommended practices to be considered in the different EU countries in view of their application along the particular national traditions and regulations.

The example chosen for the ENIQ pilot study is the qualification of an inspection of austenitic pipe to pipe and pipe to elbow welds. All aspects of the inspection are qualified. The procedure and equipment qualification involve open trials on test pieces containing defects while that of the personnel is done through blind trials. In addition to practical trials, qualification involves also the production of a technical justification as required by the methodology document.

Despite the fact that the pilot study is not finished yet there are already a number of lessons learned from the pilot study. These are:

- the importance of providing all necessary information required to conduct the inspection qualification prior to its start; this may seem self-evident but it was found out that this is an extremely important issue which in many cases is not done sufficiently
- the importance to separate the inspection procedure/equipment qualification from the complementary personnel qualification which allows to identify exactly where the weaknesses lie
- the role and function of the technical justification
- how to handle the issue of influential/essential/fixed parameters
- the advantages open trials represent with respect to blind trials :
  a) the possibility to assess in a much better way the capabilities of the inspection system
  b) reduced costs with respect to blind test pieces in view of maintaining the confidentiality of test pieces used for blind trials (requiring for example a large number of blind test pieces if many inspection teams have to be qualified)
- the fact that a technical justification for austenitic welds is inherently weaker than that for ferritic welds due to the variability of the structure of the material obliging to rely more on test piece trials
- the importance of the similarity between the structure of the qualification test pieces and that of the actual component especially for austenitic components

4. ENIQ TASK GROUP 4 ON RISK INFORMED INSPECTION

The Steering Committee of ENIQ agreed to set up a Task Group on Risk Informed Inspection. The general objective of this task group is to study aspects of ISI or any other surveillance method in view of both a more selective application and optimisation in order to reduce the inspection efforts whilst at the same time increasing the ISI effectiveness. Actions have been decided for gathering and transfer of information on the different aspects of risk informed inspection and writing of a "European methodology" document on risk informed inspection, appropriate to the needs of the European plant operators so that they can use the concept of risk to provide a process by which the plant operator can optimise the management of the risks of their plant, using thereby different methods including in-service inspection. This is done in view of harmonisation of positions on risk informed in-service inspection in the EU. It is also hoped that through the work done in the task group it is possible to develop tools to qualify and hence quantify the effectiveness of the ISI done.

The organisational framework of this task group is determined by the ENIQ agreement:

- utility driven

- linked to ENIQ but might evolve into a separate network
- narrow contact/co-operation with the regulators welcomed
- European core

R. Chapman from Rolls Royce and Associates was nominated as chairman of this Task Group. S. Crutzen acts as co-chairman of the Task Group.

5. CONCLUSIONS

Closing the reasoning with qualification again it can be stated that the use of demonstration standards is the best way to harmonize inspection in all comparable and different cases of situations with the objective of allowing the use of the best possible technologies in capability, economy and respect of the environment. The condition is that objectives would be precisely defined : inspection targets must result of correct safety analyses. This is the reason why there is a strong correlation between inspection qualification and risk informed inspection.

Qualification of inspection procedures based on NDE has obviously to be done following well codified rules. It must be applied by or under the invigilation of recognized qualification bodies working to the satisfaction of the plant operator and of the regulator. It is this set of rules proposed as recommended practices that the European Network ENIQ develops through the definition of a qualification methodology and its implementation during pilot studies.

In the same way PDI in the USA implements the principles of the Appendix VIII of the ASME Code Section XI, but with important evolution.

The IAEA proposes guidelines for the qualification of the ISI of WWER's along the European methodology. Central and Eastern European countries (CEEC's), Russia and Ukraine are actively involved in the development of qualification schemes, procedures, components, centres, training programmes due to the impetus given by the EC programmes TACIS and PHARE.

These facts allow to hope in a convergence of the qualification principles and practices in Europe, in the USA, in the CEEC's, in Russia and Ukraine and probably in other countries not yet involved in performance demonstration, to the benefit of mutual trust, of mutual recognition, of international trade and of the safety of nuclear installations.

The proposed framework for risk informed inspection/management developed in ENIQ leads to benefits that must attract the plant operators :

- Technically, the procedure leads to a selection of inspections where they can be of most use. A clear trend is the one of shifting the inspection effort towards components where the inspection would lead to an economic benefit (plant availability) besides the one of safety. Another trend is the one of replacing ineffective inspections by monitoring.
- Such a development conducted at European level will render more easy the dialogue with all plant operators and help to harmonise positions in Europe
- A harmonised approach can only promote the dialogue with the nuclear regulators or the local authorities if they can rely on concepts accepted at European level to establish the procedures of systematic assessment of plant safety.

- Last but not least risk based assessment should allow to give the targets and objectives which have to be met by the inspection and which should be verified and confirmed through qualification

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