CSNI Report No.111

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NEA

NEAR-SURFACE NON-DESTRUCTIVE EXAMINATION OF REACTOR STEELS

A State-of-the-Art Report
prepared by

J.P. LAUNAY
(Framatome, France)

for the CSNI Task Group on NDE Reliability

JUNE 1985

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
OECD NUCLEAR ENERGY AGENCY
38, boulevard Suchet, 75016 Paris, France

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The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers who have responsibilities for nuclear safety research and nuclear licensing. The Committee was set up in 1973 to develop and co-ordinate the Nuclear Energy Agency's work in nuclear safety matters, replacing the former Committee on Reactor Safety Technology (CREST) with its more limited scope.

The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries. This is done in a number of ways. Full use is made of the traditional methods of co-operation, such as information exchanges, establishment of working groups, and organisation of conferences. Some of these arrangements are of immediate benefit to Member countries, for example by enriching the data base available to national regulatory authorities and to the scientific community at large. Other questions may be taken up by the Committee itself with the aim of achieving an international consensus wherever possible. The traditional approach to co-operation is increasingly being reinforced by the creation of co-operative (international) research projects, such as PISC and LOFT, and by a novel form of collaboration known as the international standard problem exercise, for testing the performance of computer codes, test methods, etc. used in safety assessments. These exercises are now being conducted in most sectors of the nuclear safety programme.

The greater part of the CSNI co-operative programme is concerned with safety technology for water reactors. The principal areas covered are operating experience and the human factor, reactor system response during abnormal transients, various aspects of primary circuit integrity, the phenomenology of radioactive releases in reactor accidents, and risk assessment. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on power plant incidents.

The Committee has set up a sub-Committee on Licensing which examines a variety of nuclear regulatory problems, provides a forum for the free discussion of licensing questions and reviews the regulatory impact of the conclusions reached by CSNI.

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Requests for additional copies of this report should be addressed to:

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0 - INTRODUCTION

A working group has been set up to deal specifically with Nondestructive Testing reliability within the framework of the Organization of Economic Cooperation and Development and its Committee on the Safety of Nuclear Installations.

One of this working group's activities was to initiate consideration on near surface defect inspection (especially inner surfaces of reactors).

This document summarizes data received from the following countries :

. USA

. SPAIN

. NETHERLANDS

. FRANCE

. UNITED KINGDOM

. BELGIUM

. SWITZERLAND

The list of contributions is detailed in Appendix I.

The purpose of the survey was to clarify the 3 following points :

- Present regulations of safety authorities and implementation of these regulations concerning manufacturing examinations and in-service inspection. (see ASME sections III and XI, RCC-M)

- Results of R and D work already performed in this field.

- R and D work in progress and proposal for an expansion within the framework of the CSNI Special Working Group.

These 3 aspects are successively dealt with in this report.

1 - CURRENT SAFETY AUTHORITY REGULATIONS AND APPLICATION

1.1. - USA

Prior to 1981 near surface examinations were not required on U.S. pressure vessels. Examinations performed by fabricators on cladding were as follows :

. All vessel manufacturers examined the cladding from the seal mating surface. Two of the vessel manufacturers stated that dual element transducers were used for this examination. Calibration reflectors ranged from 1/32-3/32" diameter side drilled holes to 1/16" diameter flat bottom holes.

. No ultrasonic examinations of clad overlay were performed on vessel seam welds.

. All vessel manufacturers stated that cladding was given a liquid penetrant examination.

. Unbond examinations were performed on cladding only when customer purchased the examination.

In-service inspection of the near surface has been emphasized by USNRC Reg. Guide 1.150 which requires reporting of the volumes of metal not inspected and encourages, but does not require, a demonstration of the inspection equipment to find simulated cracks in the near surface region.

Techniques used are based on dual immersion probes of 60 and 70° L-waves at 2.25 MHz. The EPRI NDE Center has been involved in several demonstrations of capability and has shown good performance except on three layer manual metalarc clad when looking perpendicular to the lay direction.

U.S. vessels have manual clad circumferential weld seams and longitudinal weld seams clad with either multi-wire or strip processes. Over the weld seams only, some degree of surface preparation has been provided, usually hand grinding. Without some grinding manual cladding is not inspectable. All other clad is inspectable as welded. Only weld seams need to be inspected. Nozzle to shell welds are ground.

1.2. SPAIN

In Spain there are no special technical regulations but the regulations of the country of origin (NSSS Supplier) are enforced. So the Reg. Guide 1.150 for WESTINGHOUSE PWR on ISI and GERMAN fabrication inspections on KWU plant are to be followed.

For in service inspection, the 70 degree twin crystal, longitudinal refracted wave transducer, has been used since 1976 for near surface detection on primary piping system. On the first ISI performed on the complete Zorita reactor vessel, the 70 degrees twin longitudinal refracted wave has been used.

Main concern and greater attention has been given to the nozzle inner radius inspection : reference blocks with the curvatures and cladding similar to those to be inspected, have been used for technique development, as well as for calibration and evaluation purposes, either from I.D. or from O.D.

In Spain each group of NPP has its own set of cladded blocks (for different thicknesses) and a special inlet-outlet geometry cladded specimen.

1.3. BELGIUM

Nuclear reactors in BELGIUM are constructed as per RGPT (Règlement Général pour la Protection du Travail = Health and Safety Regulations) whereas fabrication inspection is performed in compliance with ASME Code Sections 3 and 5 and in-service inspection as per ASME 11. Each code is supplemented by complementary rules known as CCA. (For example, in instance near surface inspection of the reactor vessel, CCA's send back to several codes ASME). The Belgian authorities have opted for identical stance as that taken by FRANCE with regard underclad defects ; backed up by research program results, it is considered that no risks will arise for 20 years period ie :

- Rupture mechanics calculations to evaluate defect instability risks.

- Tests performed on parts to confirm theoretical calculations.

- Research and Development in nondestructive testing methods.

- Periodic meetings of safety authorities every 2 years and review of under-clad defect status every 5 years.

- Review of all in-service inspection results.

1.4. NETHERLANDS

In the Netherlands, nuclear power stations are not under construction at the moment and it is still unknown whether they will be built in the near future.

Therefore, the Authorities have not undertaken efforts to implement in the regulations specific requirements for manufacturing examinations intended to detect near surface defects.

However, the international developments in inspection requirements for reactor pressure vessels are closely followed (e.g. PICS-studies, 2nd Marshall report, NRC Regulatory Guide 1.150, Rev. 1 dated February, 1983).

For the two existing units in operation the requirements for the in-service inspection are based on the ASME XI code. The Authority, however, has the possibility to require additional or alternative examinations. Normally the utilities and inspection institutes, which perform the examinations, are involved in establishing and implementing these requirements.

For the reactor vessel of the pressurized water reactor type the category B-A and B-D welds are in addition to ASME XI requirements ultrasonically examined with increased sensitivity (reporting on 20% of reference level) in a zone with a depth of 50 mm under the internal cladded surface. The examination is performed from this inside surface with a 60° angle probe in stand-off technique for longitudinal and transverse defects. (The technique is chosen with regard to condition of clad-surface and available equipment for in-service inspections).

1.5. UNITED KINGDOM

The U.K. position is summed up in the CEGB proof of evidence for the Sizewell B enquiry.

Concerning nondestructive testing it shows that the capabilities of ultrasonic inspection are at least sufficient to ensure that the reactor pressure vessel enters service free from defects in the near-surface region which approaches 15 mm in through-thickness size. The principal points can be summarized as follows :

a) The forgings which make up the vessel will be free of such defects before being clad and welded together. The inspection of the vessel shell forgings is based around 0° and 45° probes ; these have been shown to give a thorough inspection, largely through the ability to inspect from the ends of the forgings with 0° probes and to detect defects by the corner effect with 45° probes. The geometries of the nozzle forgings require that some different probes be used, but the inspection principles are the same and the procedures at least as thorough. (NB : The CEGB now includes 70° shear probes for inspections of forging).

b) The intended ultrasonic techniques for use after the components have been welded together and clad are more that adequate to detect and assess subsequent defects of interest. All areas can in principle be inspected using the 70° twin crystal probes from the clad surface. Such inspections will be carried out both manually and automatically over all the main welds and over the nozzle corners and bores. In addition, over the shell forgings a proportion of the total area will be covered to ensure that controls to avoid underclad cracking have been effective (about 5% in the manual and 30% in the automated inspections). Furthermore, for the full penetration welds the corner effect with 45° shear wave probes at half or full skip is effective and will be applied in both manual and automated inspections. Finally, for the nozzle corners the additional two-probe technique is available should it be judged necessary.

1.6. FRANCE

Regulations set forth in RCC-M Code are enforced for inspection during manufacture and fabrication. The code does not explicitly require inspection of near surface zone of inner reactor surface.

The RCC-M code requires :

. 100% effective UT of welds with probe dead zones taken into consideration.

. 100% UT of cladding aimed at detecting any lack of bonding at cladding base metal interface and any lack of material density in the cladding itself.

In practice, with EDF and safety authorities agreement, the position is as follows :

- It has been proved that the risk of defects being present below cladding in base metal is now nil. No specific inspection operations are performed for locating underclad cracking.

- Potential defects in near surface zone can be caused by either cladding repairs or by the welds themselves.

- Cladding repairs are systematically inspected using L-wave probes with 70° incidence angle.

- Specific examination of weld zones close to surface is performed by making use of detection sensitivity increase obtained with corner effect. The unclad zone on either side of the weld at the time of UT has been increased to 150 mm to make the best use of this phenomenon.

- During in-service inspection the nozzle inspection machine (MIR) is used to perform specific examination of reactor vessel nozzles liable to be affected by cold cracking phenomenon. Examination is carried out under inmersion conditions using focussed probes as per the technique already described on numerous occasions (L-Wave 70°, 2 MHz).

1.7. SWITZERLAND

During In Service Inspection of the pipe welds at the reactor pressure vessel an ultrasonic technique with creeping waves was applied. This technique is accepted by the Swiss authorities for ISI of mixt welds, austenitic and carbon steel welds. This allowance was given in deviation to the Swiss rules for in service inspection until better alternative methods are available on the market. It is recognized that the inspection will detect only defects parallel and perpendicular to the weld but no intermediate orientations.

1.8. DISCUSSION

From the results of the survey performed, it can be observed that no really clear-cut regulations pertaining to near surface zone inspection on inner surface of reactor vessels exist.

However, in practice, it seems that the same techniques are selected in the various participating countries :

- Use of corner effect by UT with 45° beams prior to cladding (FRANCE and UK).

- Use of 70° longitudinal wave beams on inner surface : this type of examination can be performed with either dual element or focussed probes.

- Use of creeping waves for surface flaws.

The situation with regard to the type of defects sought and their cause is far from being identical in all countries ; this explains the big differences in practical applications of methods and specific inspection techniques.

However it should be noted that emphasis is unanimously placed on the importance taken on by near surface defect detection. Thus, the second MARSHALL report puts the stress on cladding defects : "Attention should be given to cladding integrity and thickness" ; all the works initiated in the various countries concerned, on the question of the assessment of integrity of pressure vessel (underclad defects in FRANCE, thermal shock problem in the USA, ...) do confirm that inner surface breaking defects, going through the cladding are the most severe from the fracture mechanics-point of view.

2 - MAIN RESULTS RELATING TO RESEARCH AND DEVELOPMENT WORK

2.1. INTRODUCTION

The need to obtain a better understanding of near surface defects has led many countries to set-up and perform numerous research programs. This research was carried out in four main directions :

- use and development of short focus wide refraction angle probes generating compression waves (dual element and focussed probes) ;

- research on specific techniques such as phase analysis, TOFT and crack tip signal analysis ;

- mathematical modulation of ultrasound/defect interaction ;

- research on corner effect and its use in near surface zone examination.

The results of the work described below have already been partly applied as the current near surface zone examination practices described in preceding paragraph bear witness.

2.2. STATUS OF RESEARCH IN DIFFERENT LABORATORIES

This section brings together research undertaken in research centers for improving detection of near surface defects.

2.2.1. EPRI (USA)

The EPRI sponsored work in the area of underclad crack detection and sizing has resulted in the development of several ultrasonic hardware and software capabilities that are added to that of the 70° L-ware probes. In one EPRI project digital signal processing routines have been developed to quantify and validate the underclad crack tip signals. Deconvolution is used in the visualization of the phase reversal that must exist between tip signals and in quantifying signal similarity. The complex spectrum is used in comparing the tip ensemble spectra. This work has demonstrated that valid data for sizing exhibits a predictable spectral shape. Sizing algorithms developed under this effort, when applied to the test blocks containing underclad cracks of 2.5 to 13.5 mm. depth, have produced sizing estimates with rms error of 1.7 mm.

Ultrasonic Data Recording and Processing System (UDRPS) was developed by EPRI in response to the concern with the pressurized thermal shock (PTS) issue. Although PTS is no longer a strong issue, UDRPS is however proving to be a very powerful and useful inspection tool. UDRPS records and rectified A-scan data on magnetic tape as a permanent document.

Using an X-Y scanner, the probe is scanned on parallel lines separated by 6 mm. Ten pulses are averaged in each 1.25 mm. of transducer travel. A time averaged estimate of noise level is thus formed. Over an area of 0.5 m by 0.25 m an estimate of average noise characteristic of the metal is also maintained and constantly updated as the scanner moves from scan line to scan line. Thus a noise level averaged in space and time in the immediate region is used to calculate signal to noise ratio point by point.

Metal path information is obtained by sampling each A-scan signal at 0.25 mm resolution cells. Spatial resolution is enhanced by deconvolving each date point with the use of a filter function derived from calibration data taken from side drilled holes. Detections of valid targets are declared when the signal to noise ratio exceeds a defined level and the echo dynamic curve exceeds defined persistance and matches defined slope values (as in ALOK). The centroid of each echo dynamic curve is calculated.

The three perpendicular views of the inspected volume are displayed in real time simultaneously in color (color code is dependent on signal to noise ratio). The operator inter-actively separates spatially correlated patterns of detections from the uncorrelated centroids. The data are thus separated into two sets, correlated patterns and noise. For each scan line and each centroid thus collected in the correlated set, the A-scan data are recalled from disc and examined in detail for signal to noise, location and size (crack tip diffraction). Hard copy of valid detections and sizing is reported.

Evaluation of UDRPS on near-surface cracks has been performed on four 100 mm. test blocks containing over 50 underclad fatigue cracks, saw cuts and notches. UDRPS detected all defects of 2.5 mm. depth (smallest available flaw) or larger with no false alarms. The system as tested has been to the field in October 1983 at Calvert Cliffs Unit 1. It has been air shipped across the U.S. three times with minor start-up problems and no failures after initial check-out. The system as it now exists could be used in ISI's.

The ALN 4060 Flaw Discriminator has also evaluated for the detection of underclad cracks. This is an integrated ultrasonic inspection and pattern recognition system. The ALN 4060 provides all of the functions of a manual flaw detector in addition to its capability to be trained to distinguish among up to three classes of signals. Results of limited studies show that the ALN 4060 algorithm has the ability to distinguish between clad noise signal, underclad defect signals, and slag inclusions at the clad/metal interface. The instrument's classifier trained on one set of test blocks has performed well on other test blocks.

2.2.2. *BATTELLE (PACIFIC NORTHWEST USA LABORATORY)*

The following programs are in progress at the Battelle Pacific Northwest Laboratory :

- Evaluation of pulse Echo Shear Wave and Dual Element Longitudinal Wave Technique

Under optimum conditions of ground clad, 60° and 70° contact shear wave (PE) techniques were compared with contact dual element longitudinal probe techniques. The test involved use of 12 cracks observed from both sides, thus providing 24 observations. Nine of the test cracks were thermal fatigue type cracks and the remaining cracks were produced by hydrogen cracking. All cracks had an extended depth of 12 mm below the clad/base metal interface with a 3:1 aspect ratio. The test measured the maximum flaw amplitude response.

Both shear wave pulse echo techniques not only failed to detect 25 percent of the flaws, but provided very poor flaw amplitude response and signal-to-noise ratio. The dual element longitudinal wave techniques performed much better. The 45° dual element longitudinal technique provided poor amplitude response ; however, the improved signal-to-noise ratio allowed all flaws to be detected. The 70° dual element longitudinal techniques proved to be the best performed. Using this technique, all flaws produced responses above the 1/16 in. SDH reference level.

- Time Locus Techniques

An initial evaluation of time amplitude locus principles has been performed. Detectability using time-amplitude locus curve criteria requires that the flaw echo's time-of-flight vary proportionately with the transducer's distance from the flaw. Furthermore, the flaw echo's amplitude has to remain higher than the background noise over sufficiently long amounts of probe motion to be visually distinguishable from spurious indications. The stringency of this latter criterion might conceivably be relaxed somewhat if the flaws were to be searched for computationally rather than visually (i.e., SAFT processing).

Using the time-amplitude locus technique, a 5 MHz focused immersion transducer detected thermal fatigue cracks using insonification directions parallel and perpendicular to clad lay for both the three-wire automatic and strip as-welded claddings. However, this technique could not detect fatigue cracks under the manual metal arc "as welded" cladding.

The same technique using a 2 MHz 70° zone-focusing contact transducer enabled cracks to be detected when insonified in a direction parallel to the clad lay on the manual applied shielded metal arc (SMA) cladding, but failed to detect cracks oriented so as to require insonification perpendicular to the clad lay.

- <u>Manual Ultrasonic examination</u>

Three designs of zone focusing transducers are used with beam angles of 70°, 60° and 45° ; all three transducers are 2 MHz, dual element pitch-catch type.

Results indicate that amplitude based detection of SMA clad overlay in the "as welded" condition is not reliable, also that the three-wire sub arc, and strip clad, yield a surface condition suitable for reliable detection of underclad cracks in the "as welded" condition for amplitude based detection.

Bottom tip signals can be detected through three-wire sub arc, and strip clad, while bottom tip signals cannot be detected through SMA clad left "as welded". Since tip diffracted signals are often used in sizing, this evaluation shows the potential for sizing through different conditions of cladding.

2.2.3. *TECHNATOM (SPAIN)*

Up to now, only some measurements for comparison of the different existing claddings in reactor vessels have been done. Also, calibrated fatigue cracks have started to be produced for insertion in a 80 mm thick plate.

Tests have been performed on crack detection and evaluation using immersion Eddy Current Technique on some austenitic welded piping.

2.2.4. *VINCOTTE (BELGIUM)*

The main directions of research followed in Belgium over the past few years are as follows :

Defect sizing possibilities using tip effect and longitudinal wave probes. The first program concerned weld defect sizing by UT and was carried out on large boiler components within framework of CECA research activities. A few tests were also carried out on artificial defects using contact type focused probes under immersion conditions. Contact focused probe tests proved inconclusive and currently this technique is only occasionally used for in-shop applications mostly with standard probes. This limits detection effeciency of near surface defects.

The second technique is directed towards improving longitudinal wave probes, mainly dual element L probes inclined at 70°. Up till now, depths with maximum sensitivity below about 15 mm had never been taken into consideration.

2.2.5. *RTD (NETHERLANDS)*

The development of a technique to size near surface defects is oriented towards short focus transducters and flaw tip reflection technique. The latter technique was optimized and used on representative test samples. The work was performed in cooperation with EDF Paris.

This method shows that tip and bottom location could be established with a standard deviation of 1 mm.

Detection and evaluation of small cracks below cladding can be performed by an Ultrasonic Impulse Echo Technique, using a special UPR Probe. UPR probe was developed by RTD laboratories with the following main characteristics ; 70° compression wave, 2 HHz, focus : 18 mm.

The evaluation of the depth of these cracks is not only hampered by the austenitic structure of the welded clad material and its surface condition, but also by the phenomenon that these cracks appear in clusters and the ultrasonic interference effects associated with it.

Application of a Scatter Interception Technique enables to determine whether the cracks exceed a prescribed depth. This technique can be used to monitor possible growth of such cracks, thus contributing to safe plant operation.

2.2.6. *CEA (FRANCE)*

Several research programs are underway, notably as a result of discovery of underclad defects in 1979, and consist of the following :

- development of high performance focussed transducers suitable for the detection of underclad cracks,

- data acquisition and computerized analysis method,

- significant experience has been logged through field utilisation on a routine basis, of underclad cracking examination in PWR vessel in-service inspection.

Averaging of signals has been experimented to reduce structure noise. A deconvolution method allowing to distinguish defects near to each other or to the surface, as well as measuring thickness of thin foils has been developed.

It should be noted, that focussed transducers specially developed for sizing of underclad cracks, show promise for field application. With this type of transducer, tip diffraction is enhanced.

Results are in full agreement with theory. The principle used is applicable for any type of cracks if the size in a known direction is greater-than 5 mm. Tip of cracks diffraction or "point diffraction" is a powerful method to size defects. A large development of this method is awaited during coming years in association with focussed beam. Focussed beams in conjunction with point diffraction have been used for many years by French Atomic Energy Commission and results obtained up to now are very encouraging.

- Up till now, the detection of undercladding cracks was carried out by means of ultrasonic testing, but in hypothesis of crack propagation in the cladding and taking the ultrasonic dead zone in account, an eddy current test is considered as a possibility to evaluate the crack ligament from 4 mm to zero. A low frequency eddy current method has been developed to evaluate the ligament between crack front and cladding surface and measure crack length. It uses a large surface probe to obtain a low sensibility on surface variations and a good penetration of eddy current.

2.2.7. *FRAMATOME (FRANCE)*

A comparative study carried out using conventional 60° + 45° shear wave probes (1, 1.5 or 2 MHz) enabled detection sensitivities to be established through varying several parameters.

Flat bottom holes and 0° to ± 10° open cracks with ligament distance of between 0 to 32 mm stainless steel, clad or unclad ferritic steel samples.

The first results obtained on flat bottom holes measured with respect to 2 mm side drilled holes indicate that :

- When probe is inclined, lesser sensitivity variations occur for 5 mm diameter than for 10 mm diameter flat bottom holes.

- 45° shear wave probes perform better than 60° shear wave probes. This is probably due to changes in wave mode which occur when the defect is in proximity to the surface opposite the examination surface.

An over-quotation for the defect in question is obtained. The above mentioned study demonstrated that this sensitivity increase was greater at 2 MHz frequency. Taking all frequencies as a whole, 0° inclined flat bottom holes gave best results and + 10° flat bottomed holes produced minimum effect. Eg. below is given over quotation expressed in dB for near-surface flat bottom hole (0 mm ligament) and flat bottom hole with 24 mm ligament :

- 10.5 dB (non-clad steel) and 1.9 dB (clad steel) for 5 Ø flat bottom hole detected using 45° 2 MHz shear wave probe,

- 14.1 dB (non-clad steel) and 12.7 db (clad steel) for 10 Ø mm flat bottom hole detected using the same probe.

Finally, when dealing with flat bottom reflectors perpendicular or slightly inclined with respect to skins, it should be noted that sensitivity increases as a function of defect proximity to the surface opposite that being scanned.

2.2.8. GREAT BRITAIN (UKAEA, CEGB, BABCOCK)

Reviewed here are those tests undertaken within DDT programs framework for testing and evaluating the various UT techniques.

These assemblies were examined using several techniques such as :

- diffraction echo for detection and sizing of defects near to the surface,

- refraction echo examination which is either performed using 0 and 70° longitudinal wave (this last are used in the Defect Detection Trials and PISC II by CEGB) and 45° shear wave probes or automatically using 0 or 70° dual element probes,

- time of flight technique : a plate was designed to test the capability of ultrasonic techniques for detecting and sizing defects, in the presence of austenitic cladding, in a region extending from the cladding surface to 30 mm below the austenite-ferrite interface.

With the ultrasonic time-of-flight technique, all defects extending at least 6 mm down from the cladding interface were satisfactorily detected, located and sized but interpretation of the data was very time consuming. With the high-angle compression-wave technique, defects extending as little as 2 mm from the interface could be detected and located very rapidly but not sized.

Although the time-of-flight technique is not an efficient technique for near-surface detection, no other technique is likely to give such accurate estimates of defect depth. The high-angle compression-wave technique, on the other hand, is an efficient detection technique but not a reliable sizing technique. The results of this study have confirmed that the optimum inspection strategy is to employ the high-angle compression-wave technique for detection followed by sizing by time-of-flight. If there is a possibility of defects buried wholly in the ferrite, then it may be worth employing time-of-flight for detection.

2.3. DISCUSSION

All work undertaken by the above mentioned laboratories demonstrate that 70° longitudinal wave probes are widely used and give good results. In addition, the development of signal processing techniques (averaging and increases in signal-to-noise ratio), use of crack tip signal diffraction and the TOFT technique reinforce near-surface defect detection and sizing capabilities. It is also of interest to note the over quotation effects when using 60° and 45° wave probes. This goes some way in compensating energy losses and ultrasonic beam seattering caused by the cladding-base metal interface.

Eddy current techniques should be used to back-up UT when the latter cannot be used (eg specific geometries).

3 - MAIN LINES OF RESEARCH IN THE NEXT FEW YEARS

3.1. EPRI LABORATORY

EPRI sponsored work in the area of near surface inspection will focus on the integration of the advanced technologies (both hardware and software) to augment the human operator's decisions with automatic analysis. The goal is to combine the capabilities of imaging systems with those of feature-based systems. EPRI developed imaging systems such as IntraSpect, UDRPS, and SDL 1000 ; ALN 4060 Flaw Discriminator, and crack sizing software developed for EPRI by TetraTech are all candidate technologies for integration of capabilities. Even though PTS is no longer a strong issue, these efforts will be pursued in view of the emerging interests in Plant Life Extension (PLEX) where RPV integrity plays an important role.

Fabrication of test specimens and development of procedures for validation of RPV inspection technology are among the other ongoing activities that will continue and evolve as needs dictate and technology advances. In particular, validation of theoretical models of ultrasound and flaw interactions will be an area which will receive special attention in the next few years as models continue to improve.

3.2. TECHNATOM LABORATORY

This laboratory has started to produce calibrated fatigue cracks and inserting on a 80 mm thick plate, and also to produce specimens with calibrated cracks.

After enhancement of its own equipment (Data acquisition system), it should be used for inner radius detection.

Attention is also drawn to possible developments in Eddy Current methods.

3.3. LABORATORIES OF GREAT BRITAIN

The only work at Harwell and RNL is a study of the effects of stress on the crack tip diffraction signal using compact tension specimen.

Another program with CEGB and Welding Institute includes a study of the effects of stress on the crack signals when employing pulse-echo techniques.

Development of TOFT technique should also be continued.

3.4. CEA LABORATORIES

CEA laboratories are also working on cylindrical waves originating from crack tips for defect sizing (TOFT and phase inversion methods).

Research undertaken since the discovery of underclad cracking on reactor vessel nozzles and thus near surface defects, motivated CEA to develop special probes. A study is currently underway on EDF's behalf to develop methods for measuring crack depth and monitoring crack growth using the techniques discussed above.

Studies on Eddy Current methods are developped.

3.5. RTD LABORATORY

A possible proposal for a task group study is the comparison of conventional FTR sizing technique with TOFT.

4 - CONCLUSIONS AND RECOMMENDATIONS

4.1. It is generally admitted that detection of small size defects in the zone close to the inner surface of pressure components is of great importance for safety. A specific interest should be taken in surface breaking defects.

4.2. Regulations specific to the examination of the zones close to inner surface of pressure components do not exist presently in any country.

4.3. There are lots of different examination methods already developed or in the process of being developed ; they use ultrasound or Eddy current following various techniques and are adapted to the different natures of defects detected and to examination stages (Manufacturing or In-Service Inspection).

4.4. Work under way regarding examination methods:

- to improve reliability of techniques used,
- to improve sizing both of cladding and underclad defects,
- to compare between them performances of the various methods.

4.5. Task Group on NDE reliability recommends to keep abrest of planned R and D activities in the field of Near Surface Inspection. The Task Group suggests that an expert body within the PISC organization should take a new look at the topic when the relevant results from analysis of PISC-II plates 3 and 9 become available.

APPENDIX I

LIST OF CONTRIBUTIONS

U.S.A.

James R. QUINN - Project Manager EPRI, Coordinator for US input

- Special report for CSNI (November 83)
- EPRI Report "Recommended Changes to R.G. 1.150"
- EPRI Report "Effectiveness Demonstrations for Underclad Crack Detection"

SPAIN

J.B. PEREZ-PRAT - TECNATOM SA

- Answers to Enquiry (October 83)

NETHERLANDS

A De STERKE - RTD

- Answers to Enquiry (November 83)
- Conference Proceedings :
  - "Inside Ultrasonic Inspection of Inner Nozzle Radius Conners of Nuclear Pressure Vessels"
    4th Int. Conf. on NDE in Nuclear Industry
  - Ultrasonic Inspection of Some Critical Areas of Nuclear Pressure Vessels
    5th Int. Conf. on NDE in Nuclear Industry
- Documentation on probes manufactured by RTD.

FRANCE

R. SAGLIO - CEA

- List of R and D work in progess (October 83)
- Conference proceedings
  - "Special development made in France for surveillance of subcladding defects"
    Seminar on Periodic Inspection of Pressurized Components, London October 82.

. "Methods of Signal Processing for Determination of the Dimensions of Objects Using Focussing Ultrasonic Probes" Post SMIRT Seminar MONTEREY USA - August 83.

. "Eddy Current Testing - Evaluation of Crack Propagation in Austentic Steel Cladding" 6th Int. Conf. on NDE in Nuclear Industry 83.

. "Sizing of Undercladding Cracks by Ultrasonic Testing in case of an Eventual Propagation" 6th Int. Conf. on NDE in Nuclear Industry 83.

J.P. LAUNAY - FRAMATOME

- Answers to Enquiry (October 83).

UNITED KINGDOM

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