European NDE Symposium for NPP

4–5 May 2021

The ADVISE and NOMAD projects have received funding from the Euratom research and training programnme 2014–18 under Grant Agreement No 755500 and 755330.

ADVISE Advanced Inspection of Complex Structures

NOMAD

Welcome

Dear Participants of the European NDE Symposium for NPP!

The long-term operation of existing nuclear power plants (NPP) has already been accepted in many countries as a strategic objective to ensure adequate supply of electricity over the coming decades. In this context, the effective maintenance of nuclear power plants is essential for their safe long-term operation and guarantees the level of reliability and effectiveness of all safety-relevant components and systems in accordance with their design assumptions.

ADVISE and NOMAD are two European initiatives co-funded by the Euratom research and training programme 2014–2018 under the same NFRP-01-2016 call: “Continually improving safety and reliability of Generation II and III reactors”. They fulfil requirements for nuclear safety research in the framework of assessment of long-term operation and deal with the materials characterization of components of ageing existing nuclear power plants. ADVISE and NOMAD focus on complementary topics related to non-destructive evaluation of safety-relevant components.

Additionally, successful networking is an important prerequisite for exchanging know-how with other consortia working on similar research topics, to define interaction schemes as well as to initiate further successful international cooperation and to achieve qualitatively and quantitatively high-quality cooperation.

Thank you for registering for this 2-day virtual event, which will bring together both projects, as well as a number of other initiatives and will cover NDE topics with respect to relevant materials, operation conditions and components of European NPPs for a comprehensive workshop on NDE issues for long-term operation of plants.

Sincerely,

Dr-Ing. Madalina Rabung
Chair, European NDE Symposium for NPP
Fraunhofer Institute for Nondestructive Testing

Dr-Ing. Andreas Schumm
Chair, European NDE Symposium for NPP
EDF - Electricité de France

Programme

DAY 1 - 4 May 2021 - PLENARY SESSIONS		
13:45	Welcome and Introduction	B. Valeske, M. Rabung (Fraunhofer) A. Schumm (EDF)
14:00 – 14:20 14:20 – 14:40 14:40 – 14:55 14:55 – 15:10	General aspects of reactor safety in the context of LTO in Germany General aspects of reactor safety in the context of LTO in France ADVISE global presentation NOMAD global presentation	H. Möller (GRS) T. Sollier (IRSN) A. Schumm (EDF) M. Rabung (Fraunhofer)
15:10 – 15:30	*Coffee break*	
15:30 – 16:00 16:00 – 16:30 16:30 – 17:00 17:00 – 17:10	Microstructural and mechanical property characterization of primary loop materials using NDE Physical principles of NDE methods for characterization of embrittlement Eddy Current and Ultrasound Modelling Principles Q/A	J. Wall (EPRI) K. Szielasko (Fraunhofer) E. Demaldent (CEA List)

DAY 2 - 5 May 2021 - TECHNICAL SESSIONS			
	Microstructure characterization (1/2) Chairperson: M. Lowe (ICL)	**Defect detection and characterization (1/2)** Chairperson: P. Calmon (CEA)	**Non-metallic materials (1/2)** Chairperson: R. Tschuncky (Fraunhofer)
09:00 – 09:05	Welcome	Welcome	Welcome
09:05 – 09:25	Effective Orientation Mapping of Locally Anisotropic Media from Ultrasonic Phased Array Data K. Tant (University of Strathclyde)	Weld reconstruction M. Kalkowski (ICL)	Long term monitoring of concrete structure using innovative NDT and SHM approaches: NDT-CE 4.0 E. Niederleithinger (BAM)
09:25 – 09:55	Characterization of residual stresses by means of ultrasonics I. Veile (Fraunhofer)	Transducers JF. Saillant (Framatome), V. Samaitis (KTU)	Non-Destructive Testing methods in concrete structures for the life extension of Nuclear Power Plants A. Sillero (Tecnatom)
09:55 – 10:15	NDE characterization of embrittlement by means of magnetic methods A. Gasparics (EK)	Model based defect characterization A. Velichko (UoB), R. Miorelli (CEA List)	Non-destructive testing of concrete structures – Processes, Technique Development and Machine Learning D. Algernon (SVTI)
10:15 – 10:35	Non-destructive evaluation of RPV embrittlement by means of the Thermoelectric Power Method M. Niffenegger (PSI)	Phased array imaging of complex materials S. Robert (CEA List)	
10:35 – 11:00	*Coffee break*		
	Microstructure characterization (2/2) Chairperson: A. Gasparics (EK)	**Defect detection and characterization (2/2)** Chairperson: A. Schumm (EDF)	**Non-metallic materials (2/2)** Chairperson: R. Tschuncky (Fraunhofer)
11:00 – 11:20	Fast electromagnetic models for simulation of material characterization applications A. Skarlatos (CEA)	Comparison of FMC-TFM imaging and PWI imaging by using TRL transducers and linear transducers for coarse-grained materials K. Sy (Eddyfi)	Non-destructive characterization of polymers with terahertz systems C. Stumm (Fraunhofer)
11:20 – 11:40	Microstructure- and stress-independent materials characterization in reactor safety research C. Zimmer (Fraunhofer)	Research Project PIONIC - Program for Investigation of NDE by International Collaboration S. Feistkorn (SVTI)	Ultrasound as a non-destructive tool to estimate polymer embrittlement J. Rinta-aho (VTT)
11:40 – 12:00	CASS Microstructure reconstruction V. Samaitis (KTU)	Inspection and monitoring of pipelines for defects using ultrasonic guided waves M. Lowe (ICL)	
12:00 – 12:20	Machine learning and multimethod-NDE for estimating neutron-induced embrittlement J. Rinta-aho (VTT)	Passive Guided Wave Tomography for the monitoring of corrosion in pipes B. Chapuis (CEA List)	
12:20 – 12:50	**Concluding remarks and perspectives**		

Daniel Algernon

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Short Profile

Dr.-Ing. Daniel Algernon, MBA is the head of the Nondestructive Evaluation (NDE) Laboratory of the Nuclear Inspectorate with the Swiss Association for Technical Inspections. The section focuses on analysis and R&D of NDE systems, comprising the field of application on nuclear components as well as infrastructure in general.

Abstract

Nondestructive Testing of Concrete Structures – Processes, Technique Development and Machine Learning

The nondestructive testing (NDT) in civil engineering (NDT-CE), addressing concrete components specifically, comprises interesting and essential tasks, both in the context of aging infrastructure and modern construction. NDT-CE is a subsection of NDT, which still has a low level of standardization. On the one hand, this leads to a high affinity for innovative solutions, while on the other hand, it is facing high cost pressure. With the growing range of test devices, the inclusion of NDT in quality assurance during construction or in condition assessment is continuously increasing. Furthermore, NDT is used to determine unknown component geometries or to localize components inside the structure precisely.

This talk addresses building-diagnostic NDT processes and presents current developments and tasks. While the focus is set on elastic wave methods, such as ultrasound and impact echo, key applications of electromagnetic methods, such as Ground Penetrating Radar (GPR), are also included.

The topic of Artificial Intelligence in terms of Machine Learning is particularly crucial for NDT-CE. It opens up opportunities and comes with particular challenges, which is exemplified in concepts and applications. Deep Learning solutions, consisting of several layers of neural networks, have proven their capabilities. To provide the possibilities of Machine Learning to NDT users in a practical manner, the software tool ECHOLYST A.I. is continuously developed at SVTI. It implements common Deep Learning approaches and targets the NDT-CE methods, including but not limited to impact echo as well as ultrasonics. It enables effective models to be generated efficiently. The procedure is illustrated for detection as well as for regression tasks.

Bastien Chapuis

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Short Profile

- Research Engineer, senior expert in SHM
- Chairman of the sub-commission SHM of International Institute of Welding
- Interests: guided waves, passive methods, optical fibers

Abstract

Passive Guided Wave Tomography for the monitoring of corrosion in pipes

The detection of defects in pipes by non-destructive testing techniques plays a crucial role in the prevention of rupture or leakage risks in several industries (petrochemical and nuclear in particular).

Structural Health Monitoring (SHM) is a recent approach that consists in instrumenting a structure with permanent sensors to monitor its health status throughout its life. Guided elastic waves are particularly suitable for SHM applications on thin structures (such as plates, tubes or tanks) thanks to their ability to propagate over long distances.

Our group works since several years on an original SHM approach for the detection of corrosion in pipes called "guided waves passive tomography". This technology is based on the combination of guided elastic wave tomography algorithms and a passive method such as the so-called ambient noise cross-correlation.

It allows to obtain absolute and precise maps of the thickness of an area surrounded by a distribution of sensors, without emitting waves, simply by analyzing the elastic noise that exists naturally in the pipe (due to vibrations, turbulences of the moving fluid, etc.). The type of corrosions imaged by this technique are thickness losses on extended areas.

In this communication we first present recent advances in the subject. We illustrate the performances of the technology on several experimental active and passive tomography results exploiting ambient noise induced in a fluid test loop.

Edouard Demaldent

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Short Profile

Edouard Demaldent received the PhD degree in applied mathematics in 2009. Since then, he has been working on high order boundary and finite element methods for the modelling of electromagnetic and ultrasonic non-destructive testing at CEA List, France. Since 2020, he has headed the acoustic modelling and simulation laboratory.

Abstract

Eddy Current and Ultrasound Modelling Principles

The role of simulation to assist in analysis and to demonstrate the performance of non-destructive testing processes is well established, and various software solutions are today available. The strengthening of 3D numerical approaches such as the finite element method now allows access to new configurations, sometimes beyond the limits of the fast, semi-analytical models that have already been operational for a long time. Meanwhile, the needs have evolved over the years with the demand for influence analysis of an increasing number of input parameters to deal with the uncertainties of the inspection. Thus, modelling simplification based on an idealization of the working hypotheses remains critical to achieve high computing performance required to create a simulated database. Therefore, the challenge is to find a balance between genericity and idealization of the models to ensure the best compromise between the fidelity of the simulated signal and the fastness of the computation. In this presentation we will come back to these general issues and illustrate them through two typical assesments of nuclear power plants: the inspection of steam generator tubes by eddy current and of welds by ultrasounds. The strategy for developing new simulation tools dedicated to these applications in the CIVA platform will serve as a framework. Especially, the technical advances made by CEA List within the framework of the first work package of the H2020 Advise project for the ultrasonic modeling by high order finite elements of a weld bead described at the macroscopic scale will be briefly introduced.

Sascha Feistkorn

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Abstract

"Research Project PIONIC - Program for Investigation Of NDE by International Collaboration"

PIONIC continues the performance investigations of current and emerging NDE procedures and techniques conducted in the former research programs PINC (International Program for Inspection of Nickel-alloy Components) and PARENT (Program to Assess the Reliability of Emerging Nondestructive Techniques). The overall goal of these international activities between the United States, Sweden, Finland, Korea, Japan and Switzerland was and is to quantify the NDE-effectiveness for detection and characterization of simulated stress corrosion cracks (SCC). Therefore, series of open and blind international round-robin tests (RRTs) on dissimilar metal weld (DMW) mockups with different geometries containing artificial SCCs were performed including commercial vendors, laboratories and universities. The applied procedures and inspection techniques were evaluated applying the "hit-miss"-probability of detection (POD) approach. To extend the flaw population for the performance evaluation, the use of artificial SCCs created by modeling and simulation will be investigated besides the manufacturing of real stress corrosion cracks. Both sources serve to update the POD-calculation and therefore the performance evaluation with a larger flaw database. Based on the developed procedure, a nuclear-specific guideline for performing POD-analyses for NPP-components inspections will be developed. In addition, the analysis of NDE-data will be supported by artificial intelligence. A project overview and some insights of the current research will be presented.

Antal Gasparics

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Short Profile

Main field of activity is the development of magnetic field sensing methods and their applications. I participated in two other major European projects: the MANODET project based on combination of the magnetic field imaging with the eddy current method; the NANOMAGDYE project targeted the development nanoparticle based magnetic dye and its sensing technology. I contribute to the NOMAD project with the Magnetic Adaptive Testing method.

Abstract

NDE characterization of embrittlement by means of magnetic methods

Their safety of the nuclear power plants (NPPs) long term operation is a very important aspect, especially if the extension of their lifetime has been accepted. This requires the development of reliable tools are for estimating the remaining lifetime of NPP components. Reactor pressure vessel (RPV) is the most import-ant, irreplaceable part of NPPs. The main ageing process of RPVs is the irradiation embrittlement.

This embrittlement, generated by long-term and high-energy neutrons, causes mechanical property changes: increase of hardness, yield stress, and tensile strength, and also decrease of toughness. However, testing and the evaluation of the embrittlement is a difficult task, since it is not one simple degradation mechanism but the sum of several quite different processes.

In the second generation of the NPPs, surveillance specimens are placed inside of the vesseland are withdrawn after certain periods for destructive tests. These testings consume the samples. Therefore, several efforts were performed to apply nondestructive methods to measure the rate of the embrittlement, like using the measurement of the Seebeck coefficient or application of the well-known ultrasonic technique. The most of the presently operating nuclear reactors are Pressurized Water Reactor (PWR) are made from low al-loyed steels, thus magnetic methods (hysteresis measurements, Barkhausen noise measurement, magnetoacoustics emission) can be successfully applied on them.

I summarize the novel achievements oft he NOMAD project having the focus on the Micromagnetic Multiparameter Microstructure and Stress Analysis (3MA) method and on the Magnetic adaptive testing (MAT) method.

Michal Kalkowski

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Short Profile

Michal Kalkowski is a Research Associate in the NDE Group at Imperial College London working for the ADVISE project. He obtained his PhD in Sound and Vibration from the University of Southampton in 2015, with the thesis on using structural waves to remove accretions from structures. He completed several projects as a post-doctoral fellow at the University of Southampton before moving to Imperial College London in 2017. His research interests focus on the application of mechanical waves to the characterisation and interrogation of structures. A significant proportion of his work is on developing analytical, semi-analytical and numerical models for wave propagation in a variety of contexts, such as piezoelectric waveguides, fluid-filled buried pipes, or coarsely-grained and textured polycrystals.

Abstract

Weld reconstruction

Owing to a complex solidification process, the microstructure of austenitic stainless steel welds consists of long columnar grains with varying preferential orientation. Ultrasonic inspection of such welds has always been a challenge, with grain scattering and beam deviation originating from the preferential alignment being the main obstacles. Whilst the former may be to some extent circumvented by reducing the frequency of inspection, the latter requires some a priori information on the structure of the grains (essentially, the orientation of the stiffness tensor) within the weld. In this talk, we summarise principles of ray-based inversion for austenitic welds aimed at determining local grain orientation and tensor from time of flight measurements. The method is demonstrated using several examples of typical microstructures, including a grain-scale model based on an EBSD scan of a weld. The improvement to the TFM images brought by orientation maps derived using a variety of ways explored in the ADVISE project confirms their potential to improve array inspection. We also outline the estimation of average grain size in a weld, based on attenuation. The talk concludes with a short discussion about the challenges and outlook for future work and application.

I summarize the novel achievements oft he NOMAD project having the focus on the Micromagnetic Multiparameter Microstructure and Stress Analysis (3MA) method and on the Magnetic adaptive testing (MAT) method.

Michael Lowe

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Short Profile

Michael Lowe, PhD, worked in engineering consultancy from 1979 to 1989. He then joined Imperial College and is Head of the Department of Mechanical Engineering. His research is in ultrasound NDE, with specialist interests in guided waves, scattering, and materials characterisation. He has published about 300 papers on these topics.

Abstract

Inspection and monitoring of pipelines for defects using ultrasonic guided waves

Guided Wave Testing (GWT) of pipelines was developed in the 1990s and commercialised 20 years ago, and it is now well established in use in the oil and gas and chemical industries. Its main application is the inspection for internal or external corrosion of pipe walls, exploiting waves that are guided along the pipeline. This is done using a transducer ring that is placed non-intrusively on the outside of the pipe while the test is done and the pipe remains live. This provides a very rapid test while achieving 100% coverage of the material volume. The principal use of GWT is as a screening tool: a rapid GWT inspection is used to detect the presence of significant reflectors which are then examined locally in detail using conventional methods of NDE.

An alternative approach, which is gaining increasing interest, is to use permanently-installed sensors. These can gather data autonomously and so monitor the pipelines to detect the onset and growth of any defects. This is particularly valuable at locations that are safety-critical or where repeat access for inspection is difficult, and has the potential to gather rich and informative data.

The presentation will cover the physics of the GWT method and the key developments that brought it into deployment in industry, including some practical examples of its use both for inspection and monitoring. It will then show some current developments that are in progress for monitoring, and suggest some possible future opportunities that these may bring for the nuclear industry.

Roberto Miorelli

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Short Profile

Roberto Miorelli is Research Engineer in electromagnetic modeling and machine learning (ML) within the nondestructive testing and evaluation department, University Paris-Saclay, CEA List Institute, Palaiseau, France. In the ADVISE project, is involved in WP4 in developing model-driven ML strategies applied to ADVISE inspection problems based on ultrasound testing methods.

Abstract

Model based defect characterization

Accurate defect characterisation is desirable in ultrasonic non-destructive evaluation as it can provide quantitative information about the defect type and geometry. For defect characterisation using ultrasonic arrays, high resolution images can provide the size and type information if a defect is relatively large. However, the performance of image-based characterisation becomes poor for small defects that are comparable to the wavelength. An alternative approach is to extract the far-field scattering coefficient matrix from the array data and use it for characterisation. Defect characterisation can be performed based on a scattering matrix database that consists of the scattering matrices of idealised defects with varying parameters. In this presentation, the methodology and application of two different approaches are described.

The first method is based on the statistical distribution of the defect data in polycrystalline materials, and it performs characterisation within the Bayesian framework. The second approach relies on a supervised machine learning (ML) schema based on a scattering matrix database, which is used as the training set to fit the ML model exploited for the characterisation task. The performance of both approaches is compared and discussed.

Helena Möller

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Short Profile

Dr Helena Möller is a Senior Research Manager working for the Project Management Agency at the Gesellschaft fuer Anlagen- und Reaktorsicherheit (GRS) gGmbH. Helena is active in the implementation and coordination of research programs on behalf of several German Federal Ministries, particularly in R&D management of reactor safety and nuclear decommissioning related projects.

Abstract

General aspects of reactor safety in the context of LTO in Germany

Germany will phase out nuclear energy for commercial generation of electricity by the end of 2022, however, challenges and tasks in the nuclear field will remain far beyond 2022. Hence upholding and expansion of in-depth expertise and specialized personnel will be required for many years.

While Long Term Operation (LTO) is no longer on the agenda for German nuclear power plants, it remains an important topic for reactor safety research in Germany. The funding of nuclear safety related R&D activities and the support of international cooperations are major pillars of the German nuclear competence building strategy.

This presentation introduces the motivations and goals of reactor safety research in Germany. It focuses on R&D funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and presents main goals and major topics of the program as well as selected projects relevant to LTO and NDT that are currently funded. Grants are open for universities, research organisations, TSO, industry as well es small and medium-sized commercial enterprises. National research is often complemented or embedded in international activities, that may also be supported by public funds.

Ernst Niederleithinger

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Short Profile

PD Dr rer. nat. Ernst Niederleithinger holds diploma, PhD and habiltation degrees in Geophysics. He is the head of division "NDT methods for civil engineering" at BAM and lectures at RWTH Aachen. He works on NDT and SHM applications for concrete in infrastructure and the nuclear sector.

Abstract

Long term monitoring of concrete structures using innovative NDT and SHM approaches: NDT-CE 4.0

In Germany, a large amount of reinforced and/or prestressed concrete structures are approaching the end of their life cycle. Many of them already show a significant reduction of operability or capacity. The issue is most obvious, but not limited to traffic or energy related infrastructure. These structures have to be inspected and assessed on a regular basis. More and more permanent monitoring systems are installed to follow the degradation and to give pre-warning before failure.

While the basic mandatory inspection (e. g. of bridges) is still limited to visual examination and tap tests, more advanced investigation tools as ultrasound or radar are used more and more often. Monitoring e. g. by acoustic emission systems is increasingly used e.g. for detection of wire breaks in prestressed structures. The presentation gives an overview on the state of the art and an outlook on innovative systems, including the integration in modern data processing, evaluation, display and archive systems.

Markus Niffenegger

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Short Profile

Dipl. Phys./Math. & Dipl. Mech. Eng. HTL
•Theoretical Physics and Mathematics, (Uni Freiburg, Switzerland).
•Nuclear Power Plant Technology, (ETHZ and EPFL.)
•Mechanical Engineering Science, (University of Applied Sciences Burgdorf).

•1992–today: Paul Scherrer Institut, Switzerland.
•1986–1992: Kistler Group, R&D Department, Switzerland.
•1981–1986: Swiss Federal Institut for Reactor Research (EIR) and European Laboratory for Particle Physics (CERN), Geneva.

Abstract

Non-destructive evaluation of RPV embrittlement by means of the Thermoelectric Power Method

Nondestructive evaluation (NDE) methods are widely used for inspecting safety relevant components in nuclear power plants. However, most of these NDE-methods are optimized and applied for the detection of existing cracks, but there is still no approved NDE method for the evaluation of the embrittlement of RPV steels, therefore such NDE methods are highly required. In the running H2020 project NOMAD, Ultrasonic Scattering, Electric Resistivity, Thermoelectric and Magnetic Barkhausen Noise, Non-Linear Harmonics Analysis, Micromagnetic Multiparameter NDE methods are under development, with the goal to measure neutron irradiation induced material embrittlement of RPVs through the cladding.

I will present the method and results gained by the Thermo-Electric Power Method (TEPM) developed at the Paul Scherrer Institut (PSI) in the frame of NOMAD. This method uses the change of the Seebeck Coefficient (SC) as an indicator for the material embrittlement. A clear almost linear correlation between the shift of the Nil-Ductile-Transition-Temperature (NDTT) and the change of the SC was observed. However, as all methods under investigation, the TEPM suffers from the fact that the fracture toughness of steel depends upon several irradiation effects, such as defects in the FE-matrix, precipitation of Cu-enriched clusters and segregation of P atoms at grain boundaries, having different influence on the SC. A further obstacle to apply the TEPM for the quantification of material embrittlement is that other factors, such as ambient conditions e.g. electro-magnetic induction, temperature, humidity and surface quality may influence the required very precise (in the range of nV/K) measurement of the SC.

Madalina Rabung

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Short Profile

Dr-Ing. Madalina Rabung holds a PhD in materials science and engineering at the Saarland University on nondestructive characterization of ageing phenomena in metallic materials. She has been working at Fraunhofer IZFP for 21 years in the department of Materials characterization as a scientist with the focus on electromagnetic materials characterization.

Abstract

NOMAD global presentation

The overall goal of NOMAD is the development and demonstration of a multi-method based approach that can quantify neutron irradiation-induced embrittlement by measuring through cladding under simulated field conditions. NOMAD thereby focuses on the non-destructive evaluation (NDE) of RPV steels in ageing reactors to better assess their integrity. NOMAD will provide an optional procedure to quantify the neutron-induced degradation additionally to the existing standardized methods and will contribute to the extension of the existing knowledge concerning degradation phenomena and progression of the material properties.

To this, non-broken Charpy samples of many RPV materials from surveillance programs as well as larger blocks, partially with cladding made from representative steels of Eastern and Western RPV design are made available in various irradiated conditions representing different degradation levels. A variety of NDE methods was applied to provide information complementary to those generated by destructive tests which can be performed on surveillance samples only. Being volumetric in nature and with different analysing depths, these methods can give information about the bulk material properties. The results are compared and combined across methods, samples and degradation parameters in order to define a hybrid approach and finally demonstrate it in a modular way. Several state-of-the-art regression algorithms have been tested on all collected NDE data. These algorithms include neural network regression, support vector regression, Gaussian process regression and decision tree-style regression algorithms. The first results indicate that it is possible to estimate neutron-induced embrittlement though the cladding using a combination of different non-destructive measurement methods.

Details on project results will be presented in different presentations during the Symposium.

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Short Profile

Mr Rinta-aho received his M.Sc. degree in Physics at Uni. Helsinki in 2016. At the moment, he is working as Research Scientist at VTT Technical Research Centre of Finland Ltd. His scientific interest includes quantitative NDE, ultrasound physics and artificial intelligence.

Abstract 1

Machine learning and multimethod-NDE for estimating neutron-induced embrittlement

In this study, 157 irradiated and non-irradiated Charpy specimens [1] manufactured from six different steel alloys used in the reactor pressure vessels (18MND5-W, 22NiMoCr37, A508-B, 15Kh2NMFA, HSST03 and A508-Cl2) were measured. The measurements included determining several non-destructively measurable electric, magnetic and elastic parameters. The applied non-destructive methods were Direct Current-Reversal Potential Drop (resistivity) [2], 3MA (eddy current impedance loop shape) [3], TEP (Seebeck Coefficient) [4], MIRBE (Barkhausen noise) [5], MAT (magnetic hysteresis loop shape) [5] and sound velocity. After the non-destructive measurements, the ductile-brittle transition temperature (DBTT) was determined destructively using the ISO-standard method [1].

Several different regression algorithms, including neural network regression and support vector regression, were applied to the data. The algorithms were implemented with TensorFlow and scikit-learn using Python 3.7. With these algorithms, it was possible to estimate the DBTT with the mean absolute error smaller than 20 °C. Based on the results, the method can be seen as a potential candidate for estimating neutron-induced embrittlement non-destructively.

[1] ISO-148.
[2] J. Rinta-aho et. al. Baltica XI (2019).
[3] G. Dobmann et. al. Electromagnetic Nondestructive Evaluation (2008).
[4] M. Niffenegger and H. J. Leber J. Nuclear Mat. 389(1), 62-67, (2009).
[5] I. Tomáš et. al. Nuclear Engineering and Design 265, 201-209, (2013).

Jari Rinta-aho

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Abstract 2

Ultrasound as a non-destructive tool to estimate polymer embrittlement

There is approximately 1500 km of electric cables in a single NPP. During operation, some of these cables are exposed to high level gamma irradiation. Gamma radiation is known to brittle polymers such as polyethylene used as insulator in these cables. Since the planned lifetime for a single NPP is 60 to 80 years, a low-cost method to estimate the embittlement level non-destructively is required.

While polyethylene ages, Elongation at Break (EaB) decreases and Young's modulus increases. Since sound velocity for longitudinal wave mode in homogenous and isotropic media is a function of Young's modulus, Poisson's ratio and density (Eq. 1), it can be used as a non-destructive indicator for embrittlement.

While polyethylene ages, Elongation at Break (EaB) decreases and Young's modulus increases. Since sound velocity for longitudinal wave mode in homogenous and isotropic media is a function of Young's modulus, Poisson's ratio and density (Eq. 1), it can be used as a non-destructive indicator for embrittlement.

$$v_l = \sqrt{\frac{E\,(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$$

In our study, 10 specimens of commercially available coaxial cable were exposed to gamma irradiation using two different dose rates and five different total doses. Then, the sound velocities were measured using traditional pulse-echo approach with an integrated transducer-micrometer setup developed by VTT. EaB values were measured via tensile testing by ÚJV.

The results clearly show, that sound velocity increases and EaB decreases when polyethylene is exposed to gamma irradiation. The correlation between sound velocity and EaB is linear. Based on the results, it is possible to use sound velocity as a low-cost non-destructive indicator for gamma-irradiation induced degradation of polyethylene.

Sébastien Robert

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Short Profile

I am researcher and expert at CEA in the field of ultrasonic imaging for NDT. My current work focuses on: linear or matrix arrays; imaging of complex geometries and materials; fast 3D imaging; multi-mode TFM or PWI; advanced characterization methods; real-time processing with NDT systems.

Abstract

Phased-array Imaging of Complex Materials

The quality of ultrasound imaging of welds can be strongly penalized by the dendritic structure of the material which forms during its cooling. The image of a defect is all the more degraded as a reliable description of such a medium is most of the time not possible, due to the poor knowledge on the weld at the time of inspection. In a previous paper, we demonstrated the efficiency of an optimization procedure to correct a degraded Total Focusing Method (TFM) image of a point-like reflector inside a homogeneous weld, with uniaxial grain orientation. In the present communication, the procedure is extended to defects in more realistic welds with a varying grain orientation.

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Short Profile

J.F. Saillant works at INTERCONTROLE/Framatome (Chalon-sur-Saône, France) as an R&D engineer specialized in the field of ultrasonic transducers since 2008. He was conferred the title of Framatome Expert in instrumentation in 2009. J-F SAILLANT received a Ph.D. degree in 2006 for his work on the study of multilayer piezoelectric composite structures, conferred jointly by the University of Paisley (Scotland) and the Université de Franche-Comté (France), industrially sponsored by IMASONIC (France).

Abstract

Multilayer piezoelectric technology for point-source ultrasonic transducers

Ultrasonic imaging of a complex steel structures based on Full Matrix Capture (FMC) technics ideally requires an array of acoustic point-sources and point-receivers spread over the surface of the part to be inspected. This technology is conceptually very attractive but implies that lateral dimensions of each transducer are relatively small, which makes their electrical impedances very high (several kΩ) and causes an electrical mismatch with standard 50 Ω electronics. As a result, signals become weak and noisy, producing speckled images. The use of multilayer piezoelectric element technology can potentially solve this problem as it allows to reduce the electrical impedance of a transducer by a factor of n2, where n is the number of layers. This work demonstrates the interest of using multilayer technology for use in source-point type transducers. This demonstration was carried out theoretically using Finite Element Modelling (FEM) and experimentally.

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Short Profile

Vykintas Samaitis received M.Eng. degree in measurements engineering and a Ph.D. degree from Kaunas University of Technology, Lithuania, in 2012 and 2016 respectively. He has hands-on experience on a wide variety of international projects including but not limited to ultrasonic inspection of adhesive joints, spot welds, piping networks and composites. Since 2016 he is a researcher at non-destructive testing research group at Ultrasound Research Institute. His current interests include long-range guided wave inspection, structural health monitoring, material characterization, numerical modelling, signal processing and phased array imaging.

Abstract 1

CASS Microstructure reconstruction

NDE techniques based on ultrasonic waves are widely used throughout NPP industry to detect defects such as cracks and to prolong the usage of defected components that doesn't require replacement yet. Each inspection technique needs a qualified procedure, which ensures that it's capable of detecting defects of specific type and size. However, complex and heterogeneous structures of coarse grained castings significantly degrade the performance of ultrasonic techniques. This is due to microstructures with large grains, inducing scattering of the ultrasonic waves at grain boundaries, which is responsible for both structural noise and attenuation. Local variations of grain size and orientation lead to different ultrasonic responses and limited applicability of the inspection procedures. Hence, the inspection qualification needs to cover range of grain sizes and their distributions for each specific component. This forms a need for a metric to estimate grain size and its distribution from the measurements that could be taken on-site.

In this presentation we discuss several approaches how the mean grain size can be evaluated from attenuation measurements. By combining the results from metallographic evaluation, modelling and experimental measurements we demonstrate the importance of volumetric grain size distribution and non uniqueness of attenuation metric at different combinations of grain statistics. Finally, we discuss alternative metrics and measurement approaches that could be used for assessment of grain properties and their suitability on-site.

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Abstract 2

Transducers

TRL (transmit-receive-longitudinal) transducers are the method of choice for the inspection of coarse grain cast austenitic stainless steel. Employing both an angle in the incidence plane and a roof angle, TRL transducers reduce the effective material volume generating backscatter that actually makes it back to the receiver. Introduced in early 1990s TRL transducers currently available as linear or asymmetrical matrix arrays that allow to cover different depth ranges with a single transducer. Novel TRL array technologies allow to apply advanced imaging algorithms to even further improve the S/N ratio of reconstruction. However, the potential advantages of combining TRL with advanced imaging methods, especially those derived from TFM, are not well documented yet. In this presentation we investigate the potential of TFM and super resolution methods applied on TRL inspection of heterogeneous nuclear materials. The improvements in S/N ratio, reconstruction depth and overall decrease of structural noise is demonstrated with the experimental results on NPP relevant mock-ups. With the advent of phased array technology, we discuss 0° incidence TRL arrays, that allow to streer the beam in frontal direction and to focus at different depths dynamically, without using application specific set of wedges.

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Short Profile

Dr Andreas Schumm is a research engineer and project manager with EDF R&D and has coordinated a number of national and international collaborations. He holds a PhD in electrical engineering with a specialty on ultrasound modelling, is a member of the inspection qualification commission at EDF, and a lecturer at the universities of Lyon and Manchester.

Abstract

ADVISE

The Euratom project ADVISE (2017-2021) attemps to improve the ultrasonic inspection of corrosion resistant alloys used in nuclear power plants, in particular austenitic welds and cast austenitic steels. For these materials, a complex microstructure is responsible for both structural noise and attenuation, thus significantly degrading the performance of ultrasonic non-destructive testing.

The technical objectives of the project are to increase the comprehension and modelling of complex structures, to develop new tools for material characterization, and to improve inspection and defect evaluation methods. The project recognises the potential of computer modelling of ultrasonic NDE to assist both in inspection technique design and in the evaluation of results. This is particularly well illustrated in the proposed improvements of the imaging of full matrix capture acquisitions, introducing adaptive imaging methods, backscatter filtering and inversion strategies applicable on heterogeneous structures. ADVISE proposes to use in-situ characterisation techniques to gain additional and current information about the actual structure under test. Results are capitalized in the CIVA platform and the M2M acquisition system. This presentation will give a general overview, with more detailed presentations of key results following in the technical sessions.

www.advise-h2020.eu

ADVISE
Advanced Inspection of Complex Structures

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Short Profile

- Ph. D. in Physics, M. Sc. in Nuclear Engineering and ISO certified in several NDT methods.
- From 2011 works in Tecnatom like R&D Engineer of NDT methods and Project Manager, and from 2017 is Responsible of Technological Development.
- Usual tasks are the development of NDT techniques and procedures, simulations, mock-ups design, validations...

Abstract

Non-Destructive Testing methods in concrete structures for the life extension of Nuclear Power Plants

Due to the new requirements that are being demanded of the Nuclear Power Plants for their License Renewal (LR), Life Extension (LE) and Long Term Operation (LTO), it is necessary to verify the integrity of several civil structures, such as the containment building, used fuel building and cooling towers, among others.

In general, the objectives of Non-Destructive Test methods (NDT) for the inspection of concrete structures in nuclear power plants can be arranged into: location of the reinforcement and tendons, determination of the state of the concrete matrix, determination of the corrosion of the metallic armor and detection of cracks, voids, inclusions and delaminations in the matrix of the structure.

For this, Tecnatom, based on the experience acquired in the field of NDT, has developed a set of techniques for determining the structures condition including surface hardness testing, ultrasound (transverse wave pulse-echo and transmission speed), electromagnetic methods (Ground Penetrating Radar - GPR) and non-contact techniques such as Infrared Thermography (IRT). These different inspection techniques have been evaluated over mock-ups and it has been established the complementary synergies between them for their application in a real in the field inspection.

In this work it is presented a summary of the main NDT methods to determine the integrity of concrete structures. The method and technique best suited for a given inspection has to be selected depending on the objective sought, the typical defectology of the component, the characteristics of the structure and the conditions of the inspection itself.

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Short Profile

Dr.-Ing. Anastassios Skarlatos received the diploma degree in electrical engineering from the University of Patras, Greece, in 1998 and the Ph.D. degree from the Technische Universität Darmstadt, Germany, in 2003. His research interests include the numerical modelling of electromagnetic nondestructive evaluation and material characterization techniques and magnetic materials modelling.

Abstract

Fast electromagnetic models for simulation of material characterization applications

Magnetic methods for material characterization applications seek to retrieve information for the material microstructure based on macroscopic measurements. For this reason, the numerical modelling of such methods is confronted with the solution of the electromagnetic problem in two different scales. In a micro-mesoscopic scale, the microstructural properties have to be accounted for and properly homogenized in form of a suitable constitutive relation. The instrument response is then calculated by solving the Maxwell equations in a macroscopic level, where the material behavior is taken into account by the formerly derived material law. This law is in general case a nonlinear, history dependent, relation, which has to be addressed using the appropriate numerical tools.

In order to be able to provide quantitative predictions of such measurements, and hence establish the link between material microstrure and macroscopic observables, the above described chain of models has to be assimilated in a single simulation tool. With this objective in mind, the CEA LIST has developed a number of diverse models the recent years in a number of parallel actions involving extensive collaborations within a network of academic and industrial partnerships. The purpose of this communication is to provide an overview of these recent activities, and to present the major axes of future developments.

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Short Profile

Thierry Sollier is an NDT and Nuclear Safety specialist with 35 years of professional experience.

He has worked 22 years for the French Atomic Energy Commission (CEA) at Saclay in the NDT department, mostly doing research and development on eddy current technique.

Since 2007, he is working for the French Institute for Radiological Protection and Nuclear Safety (IRSN) as a Nuclear Safety Engineer specialized in NDT. Thierry Sollier has an experience as a group manager in NDT and materials both at CEA and IRSN.

Abstract

General aspects of reactor safety in the context of LTO in France

Long term operation (LTO) of existing nuclear power plants in France is a technical, industrial and human challenge. Among other tasks, the operator needs to address the ageing mechanisms of Systems Structures and Components (SSC) which were designed for 40 years of operation for some of them. The operator has also to propose an upgrade of nuclear safety level with an aim to reach whenever possible the safety level of Generation III reactors such as EPR.

In this presentation an emphasis is given to the 4th Periodic Safety Review (PSR) of 900 MWe reactors of EDF fleet. Several SSC have been inspected, renewed, updated or added. Some modifications stem from the lessons learns of the Fukushima-Daiichi 2011 accident.

Some SSC such as the Reactor Pressure Vessel or the containment building cannot be replaced and therefore the ageing management program and the performances of NDT are of utmost importance.

After a presentation of the 4th generic PSR for 900 MWe reactors, some examples of IRSN's research programs on ageing mechanisms related to LTO are given.

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Short Profile

Christopher Stumm, M.Sc., studied electrical engineering with a focus on automation technology at the University of Applied Sciences in Saarbrücken, Germany. He has been working at Fraunhofer IZFP for six years in the field of microwave and terahertz methods, and he currently is especially concerned with high-frequency equipment and algorithmical developments.

Abstract

Non-destructive characterization of polymers with terahertz systems

Despite Germany's withdrawal from nuclear power, it still plays a decisive role in Europe. On average, about 25,000 cables with a total length of 1,500 km are installed in a nuclear power plant. In parts, these cables are exposed to rough conditions such as high temperatures and radioactive radiation. This can result in ageing of the cable insulation with embrittlement and thus to cracks and short circuits as possible consequences.

Against this background, two projects „TeaM Cables“ and „Polysafe“ were launched as part of the European research programm Horizon2020 as well as research programm by the German Society for Plant and Reactor Safety (GRS).

„TeaM Cables“ will develop a novel multiscale approach for more precise estimation of cable lifetime with focus on cables with XLPE as isolation material, which are mainly used in the newer generations of nuclear power plants.

The „Polysafe“ project focuses on cables with CSPE/EPR as isolation material, which are more common in current generations of nuclear power plants, for which the designed lifetimes were already or will be exceeded in the next years.

Fraunhofer IZFP's contribution in these research projects relates to its competence in terahertz spectroscopy; the institute performs measurements using terahertz time domain spectroscopy on artificially aged material samples and real cables. Another focus is to analyze, interpret and correlate the measurement results with reference values to determine age-specific parameters. The advantage of terahertz methods for cable characterization results from the contact-free operation over a distance of many centimeters.

The first results will be shown in the presentation.

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Short Profile

After a master's degree in non-destructive inspection, Dr Sy did her PhD at the CEA List in collaboration with M2M, now Eddyfi Technologies on TFM imaging.

Dr Sy works at Eddyfi since 2018 as R&D Engineer, in the Products & Applications group in the ultrasound imaging technology.

Abstract

Comparison of FMC-TFM imaging and PWI imaging by using TRL transducers and linear transducers for coarse-grained materials

The Plane Wave Imaging (PWI) is a declination of Total Focusing Method-Full Matrix Capture (TFM-FMC) imaging. It is particularly suited for strongly attenuating and / or noisy structures. Indeed, while the FMC excitation is based on elementary and successive transmission, the PWI excitation is based on plane wave shots in different angles using all the elements of the sensor. One of the advantages of this TFM variation is to send more energy into the specimen undergoing inspection.

The objective of this presentation is to show the benefits of PWI in the case of coarse-grained materials. An experimental evaluation on a specimen presenting a repair was carried out with TRL transducers and linear transducers. The results obtained with both techniques will be illustrated and discussed.

Klaus Szielasko

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Short Profile

Dr Klaus Szielasko has been working in the field of reactor safety research for more than 20 years. Currently he is head of the Materials Characterization department at Fraunhofer IZFP. His main background is electrical engineering, materials science and micromagnetic NDE.

Abstract

Physical principles of NDE methods for characterization of embrittlement

The aging management of safety-critical, large, expensive or irreplaceable nuclear power plant (NPP) components such as the reactor pressure vessel and primary piping like surge or spray line requires nondestructive testing and evaluation (NDT/NDE) for flaw detection and materials characterization. Over the years it has been demonstrated that NDE methods detect signs of possible embrittlement significantly before the material degradation reaches critical levels, i.e. before any damage would occur. As opposed to NDT techniques, which focus on flaw detection, NDE detects changes in material behavior and mechanical properties. This contribution focuses on the physical principles of electromagnetic nondestructive evaluation based on electromagnetic acoustic transducers (EMAT) and micromagnetic techniques such as 3MA. These techniques are sensitive for changes in microstructure and stress via acoustoelastic, magnetoelastic and micromagnetic effects. Machine learning enables the prediction of virtual degradation classes or even the quantitative approximation of mechanical characteristics like Vickers hardness and ductile-brittle-transition temperature shift after training on on reference sample sets or in reference experiments. Besides the possible application for recurrent inspection, these NDE techniques are also well suited for continuous condition monitoring at elevated temperatures and for instrumentation of laboratory experiments to understand general material characteristics in service conditions.

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Short Profile

Dr Katherine Tant is an EPSRC UKRI Innovation fellow and Chancellor's Fellow based in the Department of Mathematics and Statistics at the University of Strathclyde, Glasgow. Her expertise lies in modelling waves in complex media and developing ultrasonic tomography algorithms, primarily for non-destructive evaluation applications.

Abstract

Effective Orientation Mapping of Locally Anisotropic Media from Ultrasonic Phased Array Data

Imaging defects in heterogeneous and locally anisotropic media presents a significant challenge for the ultrasonic non-destructive testing community. When basic imaging algorithms, which typically make constant wave speed assumptions, are applied to datasets arising from the inspection of such complex media, the resulting defect reconstructions are often distorted and difficult to interpret correctly. However, knowledge of the underlying spatially varying material properties allows correction of the expected wave travel times and thus results in more reliable defect reconstructions. In this presentation, I will discuss two different approaches to reconstructing material property maps from ultrasonic phased array data, one based on a probabilistic inversion technique and the other on a deep learning approach. The resulting tomographic maps are fed into standard imaging methods and we show that the resulting defect reconstructions exhibit a significant improvement across multiple flaw characterization metrics.

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Short Profile

Dr Ines Veile is currently group manager for method development in the department Materials Characterization at Fraunhofer IZFP. She has a PhD in geophysics from Karlsruhe Institute of Technology and joined Fraunhofer IZFP in May 2015 as a reseach assistant for ultrasonic materials characterization.

Abstract

Characterization of residual stresses by means of ultrasonics

The restructuring of energy production worldwide towards increasing use of solar and wind energy is directly coupled to increasing load dynamics of fossil and nuclear power plants. This leads to a rising amount of stress-induced fatigue. The temperature-based monitoring systems applied in nuclear facilities today (such as Framatome's FAMOSi) use a load-dependent, quasi-continuously measurable physical parameter (e.g. outer wall temperature) in order to estimate fatigue-relevant time series of multiaxial loads. In certain load scenarios, e.g. in case of high-frequency temperature transients occurring at the inner wall, these methods reach physical limits of their applicability. The overall goal of the project EMUS-4-STRESS is the development of a method for determining the load-induced stress gradient originating from the inner wall of pipe components in case of fast load transients, by means of measurements at the outer wall, and finally fusing the developed approach with the existing FAMOSi technique. The high-frequency stress transients are determined using ultrasonic time-of-flight measurements. In this context, stress gradients over the cross-section of the pipe wall are taken into account. An ultrasonic time-of-flight-based approach has been developed and successfully demonstrated on a pressurized austenitic pipe of 1.4550 material (X6CrNiNb18-10). ElectroMagnetic Acoustic Transducers (EMATs) were used due to their advantageous properties for a possible application in the plant. Having investigated different wave types with respect to their suitability to determine relevant stress changes, the pipe was equipped with EMATs exciting horizontally polarized shear waves (propagation of a shear wave in the axial direction, polarization towards the circumferential direction of the pipe).

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Short Profile

Dr Alexander Velichko is a Senior Lecturer and a member of Ultrasonics and Non-Destructive Testing Research Group at the University of Bristol, UK. His research interests include mathematical modeling of propagation and scattering of elastic waves, ultrasonic imaging using arrays, defect and material characterization, and signal processing.

Abstract

Model based defect characterization

Accurate defect characterisation is desirable in ultrasonic non-destructive evaluation as it can provide quantitative information about the defect type and geometry. For defect characterisation using ultrasonic arrays, high resolution images can provide the size and type information if a defect is relatively large. However, the performance of image-based characterisation becomes poor for small defects that are comparable to the wavelength. An alternative approach is to extract the far-field scattering coefficient matrix from the array data and use it for characterisation. Defect characterisation can be performed based on a scattering matrix database that consists of the scattering matrices of idealised defects with varying parameters. In this presentation, the methodology and application of two different approaches are described.

The first method is based on the statistical distribution of the defect data in polycrystalline materials, and it performs characterisation within the Bayesian framework. The second approach relies on a supervised machine learning (ML) schema based on a scattering matrix database, which is used as the training set to fit the ML model exploited for the characterisation task. The performance of both approaches is compared and discussed.

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Short Profile

Dr Joe Wall is a Principal Technical Leader in the Nuclear Nondestructive Evaluation group at EPRI in Charlotte, NC USA. His expertise is on NDE for characterization of microstructure and mechanical properties in materials used in nuclear applications. Dr Wall is also on the faculty at Georgia Institute of Technology.

Abstract

Microstructural and Mechanical Property Characterization of Primary Loop Materials using NDE

For several years EPRI has been conducting research on nondestructive evaluation for materials characterization of materials used in power generation (nuclear, fossil, renewables). Due to environmental conditions, many of the materials and components in service can degrade unpredictably, resulting unplanned repair or replacement activities resulting from system failure. For this reason, it is of interest to use nondestructive evaluation techniques to assess the suitability of materials for continued service and/or to more accurately estimate their reamining useful life. This presentation will be an overview of recent and ongoing EPRI work on characterization of austenitic stainless steels used in light water reactor internals and primary loop piping applications using nondestructive and destructive testing. There are three focus areas: 1) thermal embrittlement of cast austenitic stainless steels used in primary loop piping, 2) irradiation induced void swelling of austenitic stainless steels used in reacotor internals and 3) irradiation induced embrittlement of austenitic stainless steels used in reactor internals. Preliminary results will be discussed as will be plans for future research.

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Short Profile

- Master of Science (M.Sc.) in electrical engineering at htw saar - University of Applied Sciences, Saarbrücken, Germany
- Research Associate at Fraunhofer Institute for Nondestructive Testing IZFP, Saarbrücken, Germany. Materials Characterization Department, Method Development Group.

Abstract

Microstructure- and stress-independent materials characterization in reactor safety research

Despite of the German phase-out from nuclear energy, the highest safety requirements for the operation of nuclear power plants in Europe are still vital for all countries. The German ministry BMWi, as a funding body, therefore supports research to maintain German expertise in the field of reactor safety. Reactor safety research aims at the safe operation of nuclear power plants during their remaining design service life (and possibly beyond). In this respect, the non-destructive testing technique 3MA, developed at Fraunhofer IZFP, has already made a significant contribution to the understanding of different aging mechanisms of component materials and their characterization. The basis of 3MA is the fact that microstructure and mechanical stress determine both the mechanical and magnetic material behavior. The correlation between parameters of magnetic and mechanical material behavior enables the micromagnetic prediction of mechanical properties and stress, both of which can decisively influence the service life.

A challenge, especially under practical conditions, lies in handling the mutually superimposed microstructural and stress-dependent influences. This superposition leads to ambiguities of the micromagnetic parameters, which in consequence, significantly impair the prediction quality. However, the practical application requires an economical solution to reduce these ambiguities. Within the scope of a BMWi-funded research project, the 3MA testing method has been extended, in particular for the relevant conditions in reactor safety, such as superimposed microstructure and stress influences. Investigations dealing with the extension of the feature extraction and machine learning methods have led to a more precise distinction between microstructural and stress-dependent influences.

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For further information on the project, please visit the project website

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