The AMES Network strategy developments within and outside the EU

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Abstract

The AMES *(Ageing Materials Evaluation and Studies)* network started its activity in 1993 with the aim of studying the consequences and the mechanisms of the ageing process in materials used for nuclear reactor components. Together with ENIQ, NESC, EPERC, it forms the so-called "Structural Integrity of Industrial Components" cluster of networks operated by the Joint Research Centre – Institute for Advanced Materials of the European Commission.

After two initial phases dedicated to the compilation of state-of-the-art reports on non-destructive monitoring techniques for thermal ageing, dosimetry, survey of regulatory requirements, predictive formulas for irradiation embrittlement, AMES has entered its third strategy phase with the 5th EURATOM Framework Program, Nuclear Fission Safety Key Action.

Most of the projects proposed for this program and sustained by the Steering committee were selected for funding.

Their focus is on the influence of chemical composition, namely phosphorus and nickel content, on the irradiation embrittlement of reactor pressure vessel materials, on the improvement of surveillance temperature measurement, on the validation of the Master Curve approach, and on ND techniques to monitor ageing of irradiated steels.

The paper describes the objectives of the new 5th Framework Program projects and how they are part of the AMES strategy, pointing out the involvement of CEEC and NIS countries.

The AMES Network

The AMES (*Ageing Materials Evaluation and Studies*) network was set up to bring together the organisations in Europe having the largest expertise on nuclear reactor materials assessment and research, with the following objectives:

- Provide information and understanding on neutron irradiation effects in reactor materials in support of designers, operators, regulators and researchers
- Establish and execute AMES projects on key subject areas
- Act as European Review Group
- Provide technical support to regulatory bodies, General Directorates of the EC and provide a basis for development of common European standards.
- Participate in collaborative programmes with the New Independent States (NIS) and the Central and East European Countries (CEEC)
- Promote of the integration of national programmes, the validation of techniques, the definition of European Standards and the validation and establishment of safe limits for mitigation measures.

For more information about the network organisation refer to [1,2].

AMES Strategy

The first phase of the strategy started in 1993: the members organised the partnership, identified the network goals and the missing state-of-the-art information in the field of irradiation and thermal ageing and annealing of NPP materials. Three AMES in-kind projects were started and carried out; among them the AMES 1G for example has produced the so called "Action Plan n. 1" on WWER RPVs which is now the basis of the EPLAF initiative, the European Plant Life Assessment Forum involving AMES and Russian organisations [3].

The second AMES strategy phase

The 4th FWP, i.e. the second AMES strategy phase, was devoted to an exhaustive review of the state-of-the-art in the field of ageing, finally contained in thirteen AMES EUR reports [4].

Some *Concerted* and *shared cost actions* (SCA) co-financed by the Nuclear Fission Safety Programme of DG XII were also proposed and executed. The final reports of these projects are now being finalised.

The following table shows a list of the projects that AMES members have completed or started within the 4th Framework Program:

Project Name	Objectives
MADAM	Generation of a conversion table of material damage indexes for possible comparison of results coming from different test programs and real operating plants.
RESQUE	Validation of Cv-N samples re-constitution techniques to obtain more experimental fracture toughness data limiting the amount of material used. Different welding and joining techniques are compared.
REFEREE	Assess the correlation between different fracture toughness properties of aged steels; Charpy impact versus dynamic and quasi-static toughness transition shifts measurements.
AMES DOSIMETRY	To harmonise dosimetry practices for ageing studies and to establish the dosimetry of AMES activities.
SINTER	Review safety related innovative nuclear reactor technology elements and design.
INTACT	Review the current research activities and the state of the art in the field of ageing of metallic components, civil engineering structures, motor operated valves, electrical equipment, data acquisition systems, cables, test installations, tools and reference laboratories.
AMES NDT	Concerted Action on ND methods to assess and/or monitor ageing of steel.

Table 1: List of AMES related Shared Cost Actions under the 4th FWP

The third AMES strategy phase: The strategy Drivers

With the start of the 5th FWP, AMES entered its third strategy phase, for which the AMES Steering Committee has identified subjects that must be considered as of priority for the development of a plant life management programme in relation to ageing.

These subjects have then been organised into six drivers addressing specific technical aspects and particular domains of competence where new project proposals must fit:

1. Target Identification

- Metallic components (RPV, Internals, Pressuriser, Piping)
- Irradiation embrittlement
- Thermal ageing

2. Mechanisms understanding

- Development of understanding of thermal ageing phenomena
- Development of deep understanding of environmental and material parameters on RPV embrittlement
- Improvement of the understanding of the embrittlement consequences of P segregation to grain boundaries in RPV steel, including synergistic effects with Cu and Ni
- Mechanisms of hardening and segregation in grain boundaries leading to embrittlement and/or corrosion of steel of internals structures due to high fluence neutron irradiation
- Role of hydrogen on in-service cracking of material used in PWR and BWR

3. Development of techniques

Considering the conclusions of the State of the Art reports, the techniques available and the results obtained, the following are the generic domains where more effort is needed or new development is required:

- Material testing: new testing methods, sampling techniques
- Damage detection techniques
- On-line monitoring techniques and procedures
- Methodologies and tools for neutron dosimetry
- Improved materials specifications, mitigation methods.

One essential aspect is the development of references that will allow the industrial application of the testing and detection techniques (next point of the strategy). In the case of ageing materials, the availability of reference material (e.g. JRQ steel) is important in order to correlate all information generated by testing.

4. Industrial validation

The AMES SC has identified the following priority items:

- Non-destructive monitoring techniques, which will be tested in the frame of multi-partner round-robin tests
- Validation of Master Curve approach for fracture toughness determination in irradiated materials

5. Information bases and management platforms

The information generated on the status of the ageing component has to be efficiently stored and made accessible. This involves therefore the elaboration and maintenance of user friendly databases and intelligent systems for the transfer, management and access to monitoring results and materials data, in combination with the information coming from the operation of the plant (first element to be considered in an ageing management scheme).

A large JRC database dedicated to test results was improved and broadened to include test types and evaluation routines suitable for the network's activities.

New projects

To cover the presented strategy, new project proposals for the 5th EURATOM Framework Program have been endorsed by the AMES Steering Committe.

The following are approved and started:

- PISA: Phosphorus influence on RPV steel irradiation embrittlement experimental study
- COBRA: Improvement of VVER surveillance representativeness by direct temperature measurement (submitted to COPERNICUS Programme)
- GRETE: Round Robin exercise on non-destructive tech. To assess and or monitor degradation of steels by irradiation embrittlement and thermal fatigue
- FRAME: Fracture Mechanics Based Trend Curves
- LIRES: Development of state-of-the art Light Water Reactor (LWR) Reference electrodes
- CASTOC: Optimisation of monitoring and control of erosion-corrosion affecting carbon-steel piping systems

Of these projects, the first two in particular will deal with RPV embrittlement and involve participants from NIS and CEEC.

PISA

This programme has the objective of improving the understanding of irradiation embrittlement by segregation of phosphorus to internal grain boundaries and reducing the impact of brittle intergranular failure mechanism on the properties of the Reactor Pressure Vessel both during service and at the end-of-life (EOL).

A wide range of reactor types of interest within Europe will be covered by the project, and a comparison of properties between western and eastern materials will be possible, as well as the standardisation of critical experimental techniques. Well understood materials properties are essential to secure the future safe operation of the NPPs at low avoidable cost, and with minimal emissions compared with altemative energy sources.

The range of the RPV steels to be considered includes the MnMoNi steels employed in European PWRs; the mild steels used in UK Magnox (steel) RPVs; and the steels employed in VVER 440's. Inter granular fracture and/or P segregation is considered to be important in plant applications involving all three reactor types.

Two CEEC AMES members are involved in the programme for their qualified experience on VVER's: NRI (Czech Republic) and AEKI (Hungary).

The approach employed to achieve this objective is to improve predictability through developing improved physical understanding of both the segregation process and any resultant change in mechanical properties. The latter is important as the presence of P in a grain boundary is thought to reduce the grain boundary cohesion. Macroscopically, as the grain boundary P level increases, this can appear as an increase in the ductile-to-brittle transition temperature measured in Charpy impact tests, or a decrease in the lower shelf toughness. The yield strength of the material is unaffected by these segregation processes. The necessary understanding will be developed through focussed experimental investigations of irradiated steels and *model alloys*, with associated modelling studies.

The project major elements are:

a) Specimen provision of both unirradiated steels and model alloys for an irradiation program and provision of relevant pre-existing irradiated material by the partners

b) Post-irradiation examination to determine the microstructural and mechanical property changes in materials (both steels and model alloys) either irradiated as part of this project or pre-irradiated materials supplied by the partners. These studies will result in a database of irradiation on the segregation of elements such as P and C to grain boundaries and the concomitant mechanical property changes. It will be necessary to investigate both the impact properties and yield strength increase. It will be particularly important to obtain an improved description of the influence of important irradiation and metallurgical variables.

c) The level of segregation on the grain boundaries at the start-of-life (SOL) has potentially an important influence on the effect of any irradiation-induced segregation on the subsequent embrittlement. This is simply because in many materials there may have to be a critical level of P on the grain boundaries before any effect on mechanical properties is observed. It is planned to undertake step-cooling studies in order to understand the effect of post-weld heat treatment on the SOL grain boundary chemistry. In addition, although it is widely recognised that thermal ageing can occur at elevated temperatures, there is still controversy as to whether the mechanical properties of components deteriorate during long service exposures at $\leq 350^{\circ}C$. Both these investigations will be combined in a thermal-ageing programme.

d) An important aspect of the project will be associated studies focussed on developing improved mechanistic understanding. This will be primarily through modelling of the segregation process and the effect of such segregation on the mechanical properties.

e) An additional major input is provided by a task on generating improved experimental techniques for certain critical measurements.

MODEL ALLOYS

This programme is being carried out by the JRC-IAM as 'enabling action' task of the PISA project in collaboration with the Russian Kurchatov Institute and VTT Finland.

The project is focussing directly to VVER and will integrate and compare results already obtained in Russia. To study the individual and common influence of Phosphorus, Copper, and Nickel on irradiation embrittlement, a set of 32 model alloys with parametric variation of their chemical composition is under investigation.

The programme foresees impact and non-destructive (STEAM) testing of fresh materials, followed by irradiation in the HFR LYRA rig and post-irradiation impact and non-destructive evaluation.

Preliminary results are currently under investigation [5].

COBRA

This project will tackle the open issue given by the uncertainty in measurement of the correct irradiation temperature to which surveillance capsules are subjected. Non-homogeneous neutron and gamma flux distribution determines indeed a temperature gradient along the capsule, and possible overheating as compared to the real conditions of the reactor pressure vessel. The latter phenomenon would produce non-conservative surveillance data.

A special direct temperature measurement system by thermocouple will be implemented in Kola NPP in order to prove the feasibility of the solution to the problem.

The consortium will include Russian, Armenian and European Institutions.

Block nr:	Cu	Ni	P
633	0.005	0.005	0.002
634	0.005	0.004	0.014
635	0.005	0.007	0.029
636	0.100	0.009	0.004
637	0.100	0.006	0.012
638	0.100	0.007	0.035
639	0.400	0.004	0.002
640	0.410	0.004	0.012
641	0.990	0.003	0.002
642	0.390	0.005	0.031
643	0.980	0.004	0.011
435	0.970	0.004	0.037
436	0.006	0.200	0.002
437	0.110	0.200	0.002
438	0.009	0.710	0.002
439	0.110	0.200	0.039
440	0.400	0.710	0.002
441	0.400	0.710	0.011
442	0.110	0.710	0.011
443	0.006	1.210	0.001
444	0.110	1.200	0.001
445	0.100	1.220	0.002
175	0.110	1.140	0.01
176	0.120	1.140	0.037
177	0.390	1.200	0.002
178	0.400	1.200	0.009
179	0.006	1.980	0.001
180	0.110	1.970	0.001
181	0.110	1.980	0.006
182	0.110	1.970	0.036
183	0.400	1.980	0.002
184	0.410	1.990	0.008
185	0.410	2.000	0.037

Fig. 1: Composition of Model Alloys under study

Other Projects Involving NIS countries

AMES members are currently involved in the two following TACIS PCP in collaboration with the Institute for Materials Strength of Kiev (Ucraine) and Kurchatov Institute (Russia):

IRLA	On-going	Transfer of western knowledge and experience to Ukrainian and Russian engineers related to reactor pressure vessel residual life-assessment and surveillance programmes of the RPV.
ENUKRA	Completed	Transfer of western knowledge and experience to Ukrainian engineer on fracture mechanics testing applied to RPV metal condition assessment.

Conclusions

AMES is a well-established European Network on the subject of neutron irradiation embrittlement of RPVs and core components and its mitigation methods. The added value given by AMES and the other networks to Safe Plant Operation issues resides in the strongly enhanced interaction among the most important national research institutions and suppliers, which have an opportunity to meet regularly and co-ordinate common actions, as well as tune independent ones in accordance with actions progressing in parallel elsewhere.

The involvement of CEEC members of the AMES Steering Committee and the collaboration with NIS research institutions on areas of VVER concern is greatly improved and established.

Key projects on the field of irradiation embrittlement have been started with the aim of understanding the influence of mechanisms affecting especially VVER RPV's. Important results will come from PISA and Model Alloys actions.

References

[1] "*The AMES Network - Background and developments of the European strategy on Materials Ageing*", F. Sevini, L. Debarberis, L. M. Davies, PLIM-PLEX Int. Conf., Madrid, 1999

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[3] Davies, L.M., Crutzen, S., von Estorff, U., van Duysen, J.C. and Sycamore, D., "EPLAF – European Plant Lifetime Assessment Forum: An AMES/EC-DGXVII Initiative", 5th Int. Conference on Materials Issues in Design, Manufacturing and Operation of Nuclear Power Plants Equipment, St. Petersburg, 7-14 June 1998;

[4] ***The AMES Reports:***

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No. 2 State-of-the-art review on Thermal Annealing - EUR 16278 EN

No. 3 Comparison of the Scientific Basis of Russian and European Approach for Evaluating Irradiation Effects in RPVs - EUR 16279 EN

No. 4 Survey of National Regulatory requirements - EUR 16305 EN

No. 5 Survey of existing, Planned and Required Standards - EUR 16313 EN

No. 6 A Review of Formulas for Predicting Irradiation Embrittlement of Reactors Vessel Materials - EUR 16455 EN

No. 7 AMES Reference Laboratory JRC-IAM/ECN Petten - EUR 16409 EN

No. 8 Dosimetry and Neutron Transport Methods for RPVs - EUR 16470 EN

No. 9 Methodology for Characterising Materials - EUR 17328 EN

No. 10 A Comparison of Western and Eastern Nuclear RPV Steels EUR 17327 EN

No. 11 Effect of Irradiation on Water Reactors Internals - EUR 17634 EN

No. 12 Dosimetry and Irradiation Programmes of AMES European Network EUR 17744 EN

No. 13 Conversion Table of Material Damage Indexation for all different European Reactor Types - EUR 18693 EN