SOTERIA is an on-going H2020 project which proposes a comprehensive research approach in order to enable nuclear power plant operators, as well as regulators, to better understand and thereby predict the ageing phenomena occurring in reactor pressure vessels and internal steels to ultimately ensure a safe long-term operation of existing European nuclear power plants.

The SOTERIA approach is based on an end-user perspective and has planned the set-up of simulation-oriented experiments aiming to validate models at different scales.

The SOTERIA consortium *is delighted to present this first edition of its newsletter. It is intended to make it a regular publication and to use it to keep our followers in touch with news and developments which relate to the SOTERIA project and to the management of materials ageing and operation of NPPs. In this and future editions, we shall be reporting on the progress and achievements of the project, its available results as well as on any event promoting further interaction with the SOTERIA experts.*

We hope that this newsletter will further trigger interest in the activities of ***SOTERIA*** *and attract regular visits to our website where news and articles are available in real time. We would also like to remind that* SOTERIA End-User Group is still open to equipment manufacturers, vendors, and operators.

The SOTERIA project partners

SOTERIA is divided into six work-packages (WP), four of which are dealing with technical aspects and aiming at answering industrial key issue of operating existing nuclear power plants beyond the originally anticipated time frame. Two additional work packages are dedicated to the project strategic and operational management (WP1) and to the dissemination and exploitation of results and training, as well as the end-user assessment and involvement (WP6).

Since the project launch in September 2015, the project partners have made significant efforts in each of these work packages. Next is a description of the major progress and achievements related to:

- Radiation effects on microstructural evolution of RPV and internals under different levels of fluence and flux (WP2)
- The evaluation of uncertainties in fracture toughness measurement on irradiated RPV steels and mitigation approaches (WP3)
- The environmental effects on IASCC susceptibility of reactor internals (WP4)
- The development, validation and integration of models to assess RPV and Internals components under irradiation (WP5)

What does SOTERIA intend to do?

SOTERIA will provide further knowledge and tools to manage the ageing of nuclear power plants by addressing 4 specific technical objectives:

1- Carry out experiments assessing neutron flux and fluence effects on reactor pressure vessels and internal steels in pressurized water reactors
2- Evaluate the residual lifetime of reactor pressure vessels by taking into account metallurgical heterogeneities
3- Assess the effect of the chemical and radiation environment on embrittlement in internals
4- Develop models for the assessment of ageing mechanisms in RPV and internals and set of an integrated computer-based platform including the new modelling tools

Progress in radiation effects on microstructural evolution of RPV and internals under different levels of fluence and flux

In this area, the activities carried out during the first year mainly consisted in selecting the materials and defining the experimental program.

During 2016, the mechanisation of samples for microstructural examinations and their transportation to the laboratories have been almost completed. First results on the flux effect on RPV steels and model alloys are already available: they confirm the trend of a decrease in cluster size and increase of number density by increasing the neutron flux.

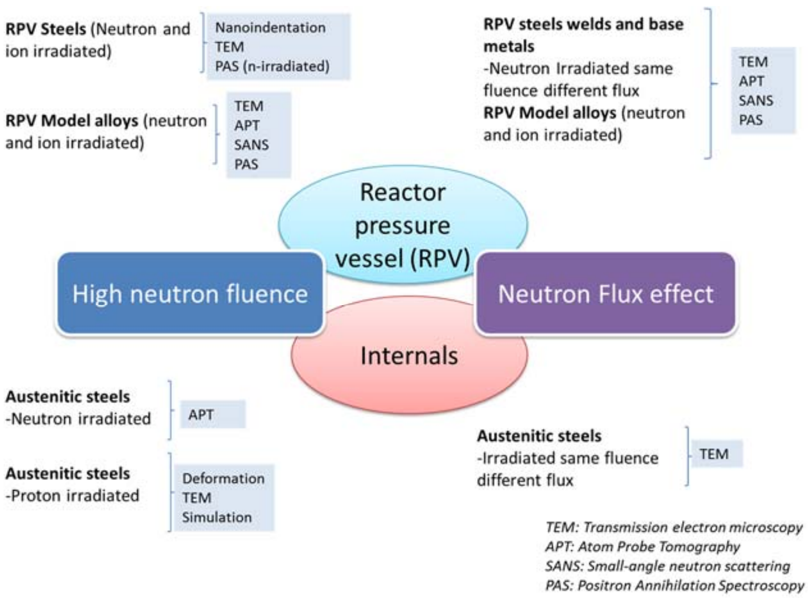

Figure 1: summary of materials and techniques related to the activities on RPV materials and internals.

First nano-indentation results on ion-irradiated RPV steels are also available: nano-indentation technique enables the detection of neutron irradiation-induced hardening. First results on PAS examination of irradiated surveillance material from a NPP were also performed. For austenitic steels, a preliminary result of TEM examinations of deformed specimens is also available.

Join the SOTERIA End-User Group!!

The SOTERIA End-User Group, an essential part of the SOTERIA project, had its very first meeting in April 2016, at the occasion of the NUGENIA Forum 2016, held on 5-7 April 2016 in Marseille, France. The User Group meeting brought together constructors, operators, research organisations, and NUGENIA members from Europe, the USA and Japan, all interested in the innovative tools developed within SOTERIA.

Representatives from the Jules Horowitz Reactor (JHR) project consortium were also present at the meeting and expressed their interest in joining the group.

By participating to this group, its members will receive first-hand information and training on the tools developed within SOTERIA and thus get the opportunity to evaluate the applicability of these tools in the industrial sector. They will also be asked to define end-user case studies based on their own experimental data (as input of models or as variable of interest).

Interested in becoming a member of the SOTERIA End-User group? Please contact Marc BERVEILLER (EDF): marc.berveiller@edf.fr

Progress in evaluating uncertainties in fracture toughness measurement on irradiated RPV steels and mitigation approaches

A summary report on baseline information on uncertainties in RPV irradiation embrittlement data was released with the outcome that initial material heterogeneities and chemical composition are the most significant uncertainties.

The majority of the unirradiated and irradiated specimens selected as representative RPV materials were manufactured and shipped to various European laboratories for mechanical testing and microstructural analyses.

Figure 2: Transport can and irradiated specimens sent to HZDR Rossendorf

Synergies with the NUGENIA project AGE60+ were identified by using bootstrapping as a promising method for handling and mitigation of uncertainties in mechanical tests. The first chemical analysis performed for some un-irradiated specimens revealed some non-negligible deviations for Cu, Ni and P which may affect the predictions of RPV embrittlement trend curves.

Progress in environmental effects on IASCC susceptibility of reactor internals

Ion irradiations performed will allow microstructural examination of grain boundaries, investigating the role of helium. Different material preparations will allow characterisation of surface oxides and improve the understanding of how they contribute to IASCC. New testing methods will allow proton irradiated materials to be tested in PWR conditions and allow characterisation of the failure modes. This data will also be compared to in-service neutron irradiated materials for verification.

Achievements in the development, validation and integration of models to assess RPV and Internals components under irradiation

During the first year of the project, simplifications of the platform tools have been carried out and the development plan presented to the project and to the User Group. Concerning the mechanical models, new improvements in the crystal plasticity law has been implemented in order to have a better prediction of the irradiation-induced hardening levels. In September 2016, some tensile tests in situ in the ESRF were performed to follow the evolution of the morphology of the microstructure of the grains during the tests. These results will be used for the validation of the mechanical behaviour of the material. Fracture models developed in SOTERIA have been applied on actual industrial data and yield useful results.

SOTERIA dissemination, exploitation, training and end-user assessment

Since project launch, the main dissemination activities comprised: the preparation of the project Dissemination and communication plan, the set-up and regular update of the public website, the creation and distribution of the project flyer and the preparation of this first newsletter. The partners attended several conferences and events and submitted several scientific abstract and publications. In addition, the kick-off Meeting for the SOTERIA End-User Group was organised at the occasion of the NUGENIA Forum 2016 held on 5-7 April 2016 in Marseille, France. Over the next period, the project will actively work on the preparation of its first public workshop. More details will be in the next newsletter…

SOTERIA building upon the PERFORM-60 platform

by Raoul Ngayam, Paul Scherrer Institut

The laboratory for reactor physics and system behaviour (LRS) is part of the Nuclear Energy and Safety (NES) Department at Paul Scherrer Institute (PSI) in Switzerland. Over years, it has been developing advanced computational methodologies in neutronics and thermal-hydraulics for the RPV. Driven by the increasingly crucial issue of long-term operation, LRS has envisaged adding materials studies in the loop to tackle RPV in-service ageing. This is described in **Figure 3**. The target of the "Material" component is to integrate multi-scale simulation advanced tools for reliable modelling and prediction of RPV steel embrittlement. A first stage in this respect has been achieved by initiating in 2014 the research project PREVENT (Physics-based modelling of REactor VEssel embrittlemeNT). One objective was to make use of currently existing advanced tools that integrate and describe at most the underlying physics of RPV ageing, in order to assess their applicability.

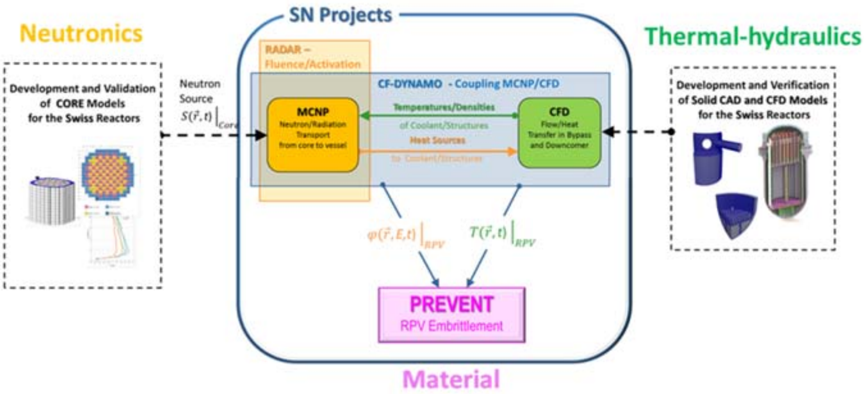

Figure 3: Schematic description of the on-going RPV projects at LRS

The simulation platform PERFORM-60 has been selected for an assessment because it represents the most recent development matching the PREVENT specifications. It is the result of the development of multi-scale modelling tools that aim at predicting the irradiation-induced embrittlement of the RPV steel taking into account all scales involved therein (from the neutron impact to the toughness shift). It is organized in modules and sub-modules that integrate in a chaining scheme various advanced models at each scale.

The assessment has been achieved by comparing and contrasting simulated and experimental transition temperature shift (ΔT_0) data of a RPV steel representative of a Swiss reactor (T_0 is defined as the temperature at which the fracture toughness is 100 $MPa.m^{1/2}$). The transition temperature shifts have been computed at various fluence levels, by subtracting the transition temperature of the unirradiated steel from that of the irradiated material, i.e. $\Delta T_0 = T_{0\_Irradiated} – T_{0\_Unirradiated}$.

The most challenging part of this work has been to set up the methodology (choice of modules and models in the platform, assumptions and simplifications) in order to describe the correct fracture behaviour of the unirradiated steel.

Once validated, the same methodology has been used to predict the behaviour of the irradiated steel.

The platform models successfully predict the fracture behaviour of the RPV steel investigated. **Figure 4** shows that the simulated T_0 has been obtained with an error of +5.07 % and -39.37 % (respectively for the unirradiated steel and the steel irradiated at the highest fluence), which is reasonable considering the various assumptions and limitations of the models used.

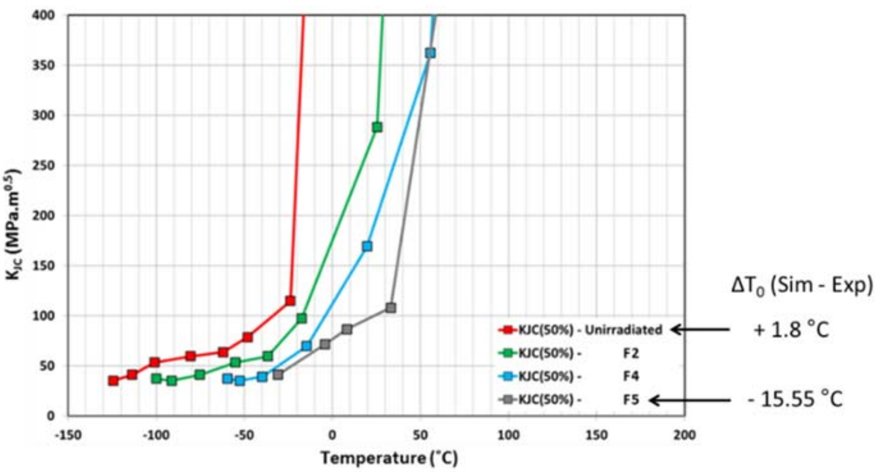

Figure 4: Results of the evolution of the fracture toughness for the un-irradiated and the irradiated RPV steels modelled by the platform at three fluences

Based on this work and from a user's point of view, our assessment of the platform has allowed identifying **some weak points that need to be tackled**:

- The platform ergonomics needs improvements, as well as guidelines based on self-explanatory indicators (e.g. level of accuracy, confidence in the results, CPU time range, etc.).
- To use the platform requires a substantial amount of preparatory work, prior to initiating a study. This work could be facilitated by integrating some case studies addressing known industrial issues and for which a predefined chaining and parameterization of modules models is provided.
- The platform lacks a tool to perform sensitivity studies and uncertainty quantification. This is essential in the field of nuclear safety to assess errors and margins.

These shortfalls should not conceal the **significant assets of the platform**:

- It is an undeniable state-of-the-art tool to help non-experts in one or more fields involved (neutronics, atomic modelling, rate kinetics, dislocation dynamics, and continuum and fracture mechanics) to assess radiation damage effects on RPV steels, with a physics-based methodology.
- The multiscale capabilities of the platform are smartly chained, several models are advanced state-of-the-art and the "black-box" integration scheme is really appreciable as it prevents the user to directly deal with the codes by themselves.
- The platform offers a great modularity, as each module (i.e. scale involved) can be an entry or exit point to start or end a study, for optimal flexibility.
- It is finally worth noting the very good trade-off between the quality of models involved and the low computational cost required for a study, which can be executed on a laptop within minutes.

"Helium Effects on 316L Austenitic Stainless Steel Fracture Mechanism"

Key Engineering Materials - Advances in Fracture and Damage Mechanics XV - ***by Jia Chao Chen et al***

Abstract. The most common fracture mechanism of nuclear reactor internals is irradiation-assisted stress corrosion cracking (IASCC). Its susceptibility at relatively low dose is dominated by conventional mechanisms such as radiation-induced segregation and radiation hardening. However, the aging of the nuclear fleet combined with the increase of their life-span reveals other mechanisms that could play an important role on IASCC susceptibility. A large amount of helium (He) can be accumulated in reactor internal components of pressurized water reactors (PWR) after long term operation. This occurrence could significantly increase (or even dominate) the IASCC susceptibility at high doses. He has been homogeneously implanted in an especially designed miniaturized specimen at 300°C up to 1000 appm. Slow strain rate tests (SSRT) results in high temperature air and in simulated PWR conditions indicate that homogenized, as-implanted He does not have a significant effect on IASCC up to 1000 appm under these test conditions.

The SOTERIA consortium includes the following organisations

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AMEC FOSTER WHEELER NUCLEAR UK LIMITED
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