Need of Reactor Dosimetry Preservation

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Abstract. The nuclear safety requirements and philosophy have changed by the development of new nuclear systems and this imposes special research and development activity. Reactor dosimetry which is applied for determination of neutron field parameters and neutron flux responses in different regions of the reactor system plays an important role in determining of radiation exposure on reactor system elements as reactor vessel, internals, shielding; dose determination for material damage study; for conditioning of irradiation; dose determination for medicine and industry application; induced activity determination for decommissioning purposes. The management of nuclear knowledge has emerged as a growing challenge in recent years. The need to preserve and transfer nuclear knowledge is compounded by recent trends such as ageing of the nuclear workforce, declining student numbers in nuclear related fields, and the threat of losing accumulated nuclear knowledge.

1. CHALLENGES OF THE NUCLEAR ENERGY RENAISSANCE

Today's nuclear renaissance in national and European aspect, expressed in building of new NPPs, as well as the development of Gen. IV nuclear reactors, meets new challenges of accuracy of the reactor analysis methods used for reliable operation and nuclear safety assessment. The nuclear safety requirements and philosophy have changed by the development of new nuclear systems and this imposes special research and development activity. The EC documents as the SET-PLAN, the SNE-TP, the "Draft nuclear illustrative programme" , "An European approach to nuclear power, safety and security" derived from "Energy Policy for Europe" [1] trace the strategic directions in nuclear knowledge management.

The growing lack of experienced employees in the nuclear field is recognised everywhere as a problem affecting the ability of the industry to retain the current high levels of expertise necessary to maintain nuclear safety. This contrasts with the Nuclear Energy renaissance. The concept could be adapted to many types of activities, but addresses the scope of the first Chapter of the Strategic Research Agenda developed within SNE-TP: Current and Future Light Water Reactors, representing Generation II and Generation III. The concept is the creation of training and professional development at a higher level, tailored for professionals with years of experience. In order to face the new challenges in nuclear safety such as reactor ageing, new fuel management, facility dismantling, waste disposal as well as the development of new generation reactors, across the world, thousands and thousands of nuclear scientists and technicians must be educated, recruited and trained without delay to quench this thirst of competence.

Nuclear Safety Culture is a topic of paramount importance for all nuclear operators as well as for all operators of installations dedicated to radiology and radiotherapy. It concerns also the regulators and related support organisations. Its efficient practice is an absolute must for nuclear power plants, for production and transport of fissile materials and radioisotopes, and for related research activities.

2. WHAT IS REACTOR DOSIMETRY

Reactor Dosimetry (RD) is an element of Nuclear Safety Culture. It is applied for determination of neutron field parameters and neutron flux responses in different regions of the reactor system plays an important role in determining of consecutive effects from the irradiation. That is, for determination of radiation exposure on reactor system elements as reactor vessel, internals, shielding; dose determination for material damage study; determination of radiation field parameters for conditioning of irradiation; dose determination for medicine and industry application; induced activity determination for decommissioning purposes.

The irradiation conditions (time of irradiation, neutron flux, neutron fluence and neutron spectra) appear as factors [2, 3] determining the radiation embrittlement of the vessel materials, and consequently limiting the Reactor Pressure Vesel (RPV) life time of light water reactors, PWR and WWER. The degradation of RPV steel properties caused by neutrons and gamma rays is due to the formation of vacancies, interstitials and transmutation reactions. Matrix damage as well as precipitation and grain boundary segregation of impurities are considered to play a major role in mechanical properties degradation of RPV steels. Thermal ageing may also combine with neutron embrittlement. The embrittlement of steels exposed to radiation fields (neutron and gamma-radiation mainly) is directly and indirectly caused by displacements of atoms from their original positions due to collisions by energetic particles. Reactor Dosimetry is an important component of the full system of methods, tools and knowledge, needed for non-destructive determination of the neutron exposure and prediction of radiation damage of the materials of reactor system, and in this way to plan ways for improving NPP lifetime extension.

Reactor Dosimetry is a field that embraces measurements and assessment of the exposure of reactor materials and reactor experiments. Areas typically covered by Reactor Dosimetry are:

- Dosimetry and retrospective dosimetry for radiation damage assessment of reactor structural materials
- Neutron and gamma-ray transport calculations, uncertainty analysis for nuclear power plant life management
- Dosimetry for core characterization and reactor physics
- Characterisation of neutron and gamma-ray environments
- Damage correlation and exposure parameters
- Monitoring of irradiation experiments
- Benchmarking, calibrations and standards
- Advanced reactors and neutron sources

The reactor dosimetry, through calculations and measurements, provides a good enough description of the neutron field parameters of the RPV environment [4].

Regarding the reactor vessel two main inputs are required to assess the embrittlement condition of the vessel metal:

- Neutron fluences at critical locations: these are determined via RD measurements and evaluations.
- Material behaviour, determined from mechanical testing and evaluation of irradiated representative steel specimens.

3. INSUFFICIENCIES OF RD

The main insufficiencies of RD address to two very different problems: need of some methodology improvements together their verification, and growing lack of human resources.

Regarding the RD which application is the reactor metal damage assessment for life time prediction the main insufficiencies of RD address the WWERs RPV neutron fluence determination. Particularly, this is related with insufficiencies and difficulties of the surveillance approach as:

- no direct measurements on RPV and internals;
- shortcomings of surveillance assemblies’ design and location;

- relatively short half life (312 days) of the radio-nuclide 54Mn available in the metal;
- very complex construction of the RPV and surveillances with very different material properties and associated design uncertainties.

More complicate is the problem with human resources. Some negative processes from the near past as the world tendency of receding of the nuclear as well as financial non-attractiveness of nuclear profession have lead to specialists' number decreasing. It has been observed a decrease of knowledge and expertise in RD during the last decade. Senior engineers and scientifics retired and no proper human resources, means and tools have been set up to remedy the situation. It is obvious that one generation is missing between the well experienced and the new researchers, who have to continue the works needed for maintaining and development of the nuclear field, in particular of RD. The management of nuclear knowledge has emerged as a growing challenge in recent years. The need to preserve and transfer nuclear knowledge is compounded by recent trends such as ageing of the nuclear workforce, declining student numbers in nuclear related fields, and the threat of losing accumulated nuclear knowledge.

4. GOOD PRACTICE AND LESSONS LEARNED

The neutron fluence evaluation methodology have been developed under various research projects of IAEA, EC Euratom (AMES [5], MADAM [6], RETROSPEC [7], REDOS [8], COBRA [9], RADE [10], COVERS [11]) and national funds in close collaboration of working teams from Russia, Czech Republic, Germany, Spain, Belgium, Bulgaria, Hungary, Netherlands and Ukraine. They were a good base for verification of the methods and development of common methodology for NPP life time management. WWERs RPV benchmarks [12, 13] were created and developed on the base of Mock-ups created at the critical assembly LR0, INR (Rez, Czech Republic). The Mock-ups simulate the irradiation conditions of VVER-440 and VVER-1000 vessels. They were used for validating and improving the methodology for RPV neutron fluence evaluation. The works were done under research projects such as "Reactor Vessel Dosimetry Benchmarks for Commercial VVER-440 Plants" sponsored by USA NRC (1995-1997), RER/4/017 [14] of IAEA, TACIS [15] and REDOS.
In particular, the verified RD methodology has been being applied for Kozloduy NPP for evaluation of the RPV neutron fluence and justification of the safe lifetime of Units 1 to 4 with WWER-440 and Units 5 and 6 with WWER-1000.

The European Working Group on Reactor Dosimetry (EWGRD) has played an important role to give a forum for exchanging ideas and discussing the current results. EWGRD is being leaded by SCK-CEN, Mol, Belgium. The west EWGRD was enlarged since 1994 by the Working Group on Reactor Dosimetry for WWER (WGRD-WWER) of the countries operating WWERs. The WGRD-VVER group, with headquarters in INR, Rez, Czech Republic, was created in 1990. In the frames of groups' activities during the past period more than twelve workshops and meetings have been held where new results, tasks and features were presented, discussed, and planed for further study. These common activities sharply were reduced if not disappeared the last four years except the International Symposium on Reactor Dosimetry (ISRD) organized every three years by EWGRD and ASTM, USA.

5. OVERCOME METHODOLOGY INSUFFICIENCY

To overcome the insufficiencies of the reactor dosimetry methodologies, improvements based on enhanced calculational dosimetry tools, innovation of experimental methods and approaches as well as creation of new benchmarks are needed.

Regarding the reactor vessel further improvements have to be developed using the results of projects TACIS and RETROSPEC, applying advanced calculational and experimental RD methods and approaches as well as creating new benchmarks. The improvements of the RD tools should reduce the neutron fluence uncertainty and in this way to support NPP lifetime extension.

The improvement of the surveillance methodology as a part of the NPP lifetime justification should be based on combined “niobium”, “diamond” and “manganese”dosimetry application [4]. The using of diamond detectors for neutron fluence measurements was proposed by RRC Kurchatov Institute [16], and now this method is in process of development. The diamond can integrate the neutron fluence over a long period of irradiation. The “niobium” method [17] could be applied for the cladding of the VVER RPV containing sufficient amount of niobium.

Creation of a concrete shielding benchmark using the VVER-1000 LR-0 Mock-up is a necessary task for thermal neutron dosimetry in NPP concrete biological shielding, for solving decommissioning problems, for an assessment of accumulated activity, as well as for optimization of locations and design of control system detection devices used in reactor start up.

The adjustment of WWER RPV neutron fluence based on activities induced during the operation has to be developed and improved by including additional and/or updated information. Application of sets of neutron monitors with expanded specification and different shape, gamma scanning of all specimens and neutron flux measurement in the RPV cavity will characterize more precisely the azimuthal and axial neutron field.

The reactor dosimetry improvements could reduce the neutron fluence uncertainty and thus substantiate the extension of NPP lifetime.

Harmonization of calculation methods used in WWER, PWR and BWR design will give more confidence in the results and better conditions for decision making. Creation conditions for participation in joint projects under EC on comparative tasks and measurements should permit to establish common criteria on the reliability of the results and the uncertainty of the evaluations. Establishing sustainable forum for developing harmonized technical procedures is one of main task of EC FP6 NULIFE [18] project.

The safety requires common vision, harmonized approaches and criteria which should be basis for reliable assessment and decision making. Therefore, there is a growing need to set a general framework to provide measures to strengthen these Community efforts and to promote common safety approaches, targets, criteria and assessment methods consistent with the best European and international safety practices.

6. OVERCOME HUMAN RESOURCES

More active creation and development of human resources in nuclear are needed nowadays in order to be able to meet the demands of the nuclear energy renaissance and modern applications in medicine and industry. The management of nuclear knowledge has emerged as a growing challenge in recent years. The need to preserve and transfer nuclear knowledge is compounded by recent trends such as ageing of the nuclear workforce, declining student numbers in nuclear related fields, and the threat of losing accumulated nuclear knowledge. Reinforcement of science and technology potential of many EU institutes is needed so to be able to support the nuclear operators and nuclear regulator in safety assessment as well as to strengthen the utilization of the research reactor for medicine and industry purposes.

The ways to preserve and develop the RD knowledge are not very easy because they need governmental understanding as well as finance supporting to:

- Maintain RD community by joint workshops and training, involving the major in experience and age researchers in lecture preparation and the young in training. The workshops and conferences are needed to facilitate knowledge sharing and network building,
- Maintain RD experience by commom intercomparisons,
- Develop RD competency by works on improvements based on common research projects,
- Involve more young researchers.

Young scientists and engineers urgently has to be attracted to the field of reactor dosimetry in order to transfer and further develop the available know-how. The interest of young researchers could be find between: receiving additional financial support, doing new professional contacts, involving in team work, involving in research/work community, creating feeling for usefulness and necessity, create feeling for proper pride.

The ways to preserve and develop the RD knowledge could be asked in the good practice of the near past within the European EWGRD, members of which are research organizations of the countries in Europe operating WWER, PWR and BWR type reactors. Joint workshops and training, commom intercomparisons will maintain the RD community experience and competency. Common research projects of the IAEA and EC will be a good base for development of common methodology as well as for involving more young researchers.

7. IMPACT

Further RD development and training will support establishing sustainable forum for developing harmonized technical procedures directed at the nuclear energy industry and national regulators, and expertise for the customers in the nuclear field. A major future challenge with a potential impact on nuclear reactor safety is the ageing of the present population of NPPs. A key component is that the integrity of the reactor pressure vessel needs to be ensured. The more the nuclear power plants age, the more neutron embrittlement of reactor components (RPVs as well as internals) becomes a crucial consideration for the prolongation of safe reactor operation. That is why a better understanding for improvement of reactor models for better defining of plant life resources is needed.

The RD improvements will permit to reduce the neutron fluence uncertainty and in this way to substantiate the extension of NPP lifetime. This will lead to better economical results based on additionally electricity production and consequently higher profit.

The RD researches and join activities could be a base for future improvement of the methodology for NPP lifetime assessment for long term sustainable utilization of the power fission reactors, when programs for modernization and lifetime extension of existing NPP, construction of 3rd and 4th generation reactors, as well as plans for decommissioning and clean-up of ageing facilities have to be created.

REFERENCES

[1] An Energy Policy for Europe http://ec.europa.eu/energy/energy_policy/index_en.htm

[2] Amayev, A.D., Kryukov, A.M., Levit, V.I. and Sokolov, M.A. (1993) ‘Radiation stability of WWER-440 vessel materials’, In: An international review (Fourth Volume) (pp. 9–29), Philadelphia, PA (United States), ASTM STP 1170, American Society for Testing and Materials.

[3] Debarberis, L., Sevini, F., Acosta, B., Kryukov, A. and Erak, D. (2005) ‘Fluence Rate Effects on Irradiation Embrittlement of Model Alloys’, International Journal of Pressure Vessels and Piping , Vol. 82, pp. 373–378.

[4] Ilieva, K., Belousov, S., Ballesteros, A., Osmera, B. and Zaritsky, S. (2009) “Reactor Dosimetry for VVERs RPV Lifetime Assessment”, Progress in Nuclear Energy, PNUCENE-D-07-00043, Elsevier Editorial, Vol. 51, No. 1, pp.1-13.

[5] AMES Project of Euratom FP-5: Thematic Network on Ageing, 2001-2004

[6] A. Ballesteros, H.Ait Abderrahim, L.Debarberis, T.Lewis, C.Sciolla, T.Seren, M.Valo, W.Voorbraak, B.Acosta, Conversion Table of Material Damage Indexation for all Different European Reactor Types, EUR 18693bEN - February 1999

[7] MADAM Project of Euratom FP-4

[8] Antonio Ballesteros, Wim Voorbraak, Luigi Debarberis, Dosimetry and Irradiation Programmes of AMES European Network, EUR 17744EN - December 1997

[9] RETROSPEC Project of Euratom FP-5: ”Retrospective Dosimetry focused on the Reaction 93Nb (n, n’)93mNb”, 2000.

[10] W., Kekki, T., Seren, T., Van Bocxstaele, M., Wagemans, J. and Woittiez, J. “Retrospective Dosimetry of fast neutrons focussed on the 93Nb(n,n')93mNb reaction”. NRG report 20576/03.53641/C, NRG Petten.

[11] REDOS Project of Euratom FP-5 “Reactor Dosimetry: Accurate determination and benchmarking of radiation field parameters, relevant for reactor pressure vessel monitoring”, 2001-2004.

[12] Ballesteros, A., Jardí, X., Böhmer, B., Konheiser, J., Ošmera, B., Kyncl, J., Keresztúri, A., Hordosy, G., Ilieva, K., Belousov, S., Kirilova, D., Mitev, M., Petrov, B., Acosta, B., Smutný, V., Polke, E., Zaritsky, S., Töre, C., Ortego, P. (2005), Reactor Dosimetry: Accurate Determination and Benchmarking of Radiation Field Parameters, Relevant for Pressure Vessel Monitoring (REDOS). AMES Report n.17, EUR 21771 EN.

[13] COBRA Project of Euratom FP-5 “Consolidation of Scientific and Technological Expertise to Assess the Reliability of Reactor Pressure Vessel Embrittlement. Prediction in particular for the Arctic Area Plant”, 2003-2005.

[14] Ballesteros, A., Bros, J., Debarberis, L., Sevini, F., Erak, D., Gezashchenko, S., Kryukov, A., Shtrombakh, Y., Goloschapov, S., Ionov A., Pytkin, Y., Anikeev, Y., Banyuk, G., Plusch, A., Gillemot, F., Tatar, L., Petrosyan, V. (2006), Consolidation of Scientific and Technological Expertise to Assess the Reliability of Reactor Pressure Vessel Embrittlement Prediction in Particular for the Arctic Area Plant Nuclear Engineering and Design, Volume 235, Issues 2-4, February 2005, Pages 411-419.

[15] Project RADE of Euratom FP-6: “Use of RPV Dosimetry Benchmark’s Results for Determining Radiation Embrittlement Damage”, 2006.

[16] Krassimira Ilieva, Sergey Belousov, Antonio Ballesteros, Bohumil Osmera, Sergey Zaritsky. “Reactor Dosimetry For VVERs RPV Lifetime Assessment”, Progress in Nuclear Energy, An international Review Journal. PNUCENE-D-07-00043, Elsevier Ltd.Editorial, Volume 51, Number 1, pp.1-13, 2009, Obtained through the Internet: http://www.sciencedirect.com.

[17] COVERS Project of Euratom FP-6: “VVER Safety Research”, 2006-2008

[18] Zaritsky, S., Belousov, S., Brodkin, E., Egorov, A., Ilieva, K.,, Kam, F.B.K., Krysl, V., Osmera, B., Smutny, V., Valenta, V., Zaritskaya, T. (1998), WWER-440 Pressure Vessel Dosimetry Benchmarks: Calculations and Analysis, Volume. I, p. 425- 432. Technologies for the New Century, ANS Radiation Protection and Shielding Division Topical Conference, Nashville Tennessee, USA, 19-23 April.

[19] Ošmera B., Marik M., Cvachovec F., Tsofin V., Lomakin S., Zaritsky S., Egorov A., Brodkin E. (2006), Experimental and Calculation Investigations of the Space-Energy Neutron and Photon Distribution in the Vicinity of Reactor Pressure Vessel and Surveillance Specimen Box of New Type in the WWER-1000 Mock-Up. Journal of ASTM International, Vol. 3, No. 3, paper ID JAI13481. Available online at www.astm.org

[20] RER/4/017 Regional Project of IAEA “Database for VVER-1000 Reactor Pressure Vessel”, 1997; “Development of WWER-1000 Reactor Dosimetry Benchmarks”, 1997-2000.

[21] Osmera, B. Lysakov V., Cvachovec F., Hudec F., Jansky B., Mikus J., Novak E., Posta S., Turzik Z., Hort M., Krysl V., Smutny V., Zaritsky S., Alekseev N., Gurevic M., Egorov A., Brodkin E., Ilieva, K., Belousov, S., Kovbasensko J., Akira Uritani, Tsuyoshi Misawa, Chizuo Mori. “Data Base for WWER-1000 Pressure Vessel IAEA Regional Project RER 4/017” Reactor Dosimetry, ASTM STP 1398, John G. Williams, David W. Vehar, Frank H. Ruddy and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshohoken, PA, 2001, pp. 312-319

[22] TACIS: SRR2/95 and R2.06/96 Projects of Euratom “Surveillance Programme for VVER-1000 RPV”, 1995-2005.

[23] V.A.Nikolaenko, S.M.Zaritsky, I.V.Bachuchin. "Evaluation of Diamond Detectors for Fast Neutron Fluence Measurements in WWER-1000 Surveillance Assemblies". Journal of ASTM International, Vol. 3, No. 6, (May 2006), paper ID JAI13437. Available online at www.astm.org

[24] Voorbraak, W., Woittiez, J., Wagemans, J., Van Bocxstaele, M., Seren, T. and Kekki, T., "Retrospective dosimetry of fast neutrons focussed on the reaction 93Nb(n,n')93mNb", in proceedings of FISA-2003 EU Research in Reactor Safety, http://www.cordis.lu/fp5-euratom/src/ev-fisa2003.htm, 2004.

[25] NULIFE Project of Euratom FP-6: “Nuclear plant life prediction”, 2007.