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Strengthening the SSTC NRS Scientific and Technical Potential through Participation in the IAEA Coordinated Research Projects

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The State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS), a Ukrainian enterprise with a 29-year experience in the area of scientific and technical support to the national nuclear regulator (SNRIU), has been actively involved in international research activities. Participation in the IAEA coordinated research activities is among the SSTC NRS priorities. In the period of 2018–2020, the IAEA accepted four SSTC NRS proposals for participation in respective Coordinated Research Projects (CRPs). These CRPs address scientific and technical issues in different areas such as: 1) performance of probabilistic safety assessment for multi-unit/multi-reactor sites; 2) use of dose projection tools to ensure preparedness and response to nuclear and radiological emergencies; 3) phenomena related to in-vessel melt retention; 4) spent fuel characterization.

This article presents a brief overview of the abovementioned projects with definition of scientific contributions by the SSTC NRS (participation in benchmarks, development of methodological documents on implementing research stages and of IAEA technical documents (TECDOC) for demonstration of best practices and results of research carried out by international teams).

Keywords: dose projection tools, IAEA coordinated research projects, in-vessel melt retention, multi-unit (multi-reactor) site, spent fuel characterization.

Introduction

The SSTC NRS as a Technical Support Organisation to the Ukrainian nuclear regulator (SNRIU) has permanent and wide interest in developing and strengthening its scientific and technical research potential for further effective use of the accumulated knowledge, skills and experience primarily for the benefits of the safety regulation system in Ukraine.

With this strategic approach, the SSTC NRS focused many of its efforts on establishing, developing and expanding international cooperation. Partnership of the SSTC NRS in research activities has been growing steadily through various bilateral projects, involvement in projects under the EURATOM research and training programmes, and participation in the IAEA coordinated research activities.

During the last decade, the IAEA extensively used Coordinated Research Projects (CRPs) as an effective international cooperation instrument to organize and support implementation of coordinated research activities in several priority areas of common interest for developing and developed Member States.

Through the CRP scheme, the IAEA implements a coordinated approach to the topical research providing a simple, direct and prompt procedure for research proposers to get involved in coordinated research activities by contributing with complementary research projects.

The SSTC NRS' first experience with CRP refers to the project «Testing of the TRANSURANUS Computer Code by Joint Solution of Test Problems within FUMAC project» implemented in 2014–2017. The SSTC NRS contributed by preparing a computer benchmark for advanced WWER-1000 fuel (TVSA-12) for rods with and without gadolinium and maximal energy release, and performing calculations relevant for FUMAC.

Since 2018, the SSTC NRS participation in the IAEA coordinated research activities has been expanding year by year. At the beginning of 2021, the SSTC NRS is carrying out four research contracts contributing to the following CRPs:

1. CRP I31031 «Probabilistic Safety Assessment (PSA) Benchmark for Multi-Unit/Multi-Reactor Sites (MUPSA)»;
2. CRP J15002 «Effective Use of Dose Projection Tools in the Preparedness and Response to Nuclear and Radiological Emergencies»;
3. CRP J46002 «Developing a Phenomena Identification and Ranking Table (PIRT) and a Validation Matrix, and Performing a Benchmark for In-Vessel Melt Retention (IVMR)»;
4. CRP T13018 «Spent Fuel Characterization (SFC)».

The main information on the aforementioned CRPs is presented below with a more detailed description of the research contributions already made to date and expected from the SSTC NRS in the implementation of a particular CRP.

CRP I31031 «Probabilistic Safety Assessment (PSA) Benchmark for Multi-Unit/Multi-Reactor Sites» (2018 – 2022)

The IAEA call for proposals for participation in this CRP (November 2017) defined its scope as to share expertise and participate in common benchmark calculations. These calculations will involve the development of Multi-Unit/Multi-Reactor Probabilistic Safety Assessment (MUPSA), based on single-unit PSAs available in Member States. The researchers from 14 countries participate in this MUPSA project: Argentina, Canada, China, Finland, Ghana, Hungary, India, Pakistan, Republic of Korea, Romania, Russian Federation, Tunisia, Ukraine and United Arab Emirates.

At many NPP sites, several units/ reactors of the same or different designs, types or age are located. As ordinary practice, so far PSAs have been performed for single NPP units to estimate the risk arising from their damage. To determine the risk for a site with multiple units/reactors, the risks of individual units were summed up or combined. Potential interactions during emergency at a multi-unit site (especially due to external impacts) were not taken into consideration. No assessments of risks arising from the equipment shared between the units were made. The IAEA publications [1], [2] advise that multi-unit effects have to be considered but they have not been instrumented for practical performance of such analyses. The benchmark exercise initiated by the IAEA as CRP MUPSA supports international knowledge exchange, and is expected to facilitate improvements in the PSA methods. The main novel research aspect in this CRP is evaluating qualitative insights for safety based on MUPSA in the context of specific site/layout features.

In the MUPSA project, SSTC NRS participates in the following tasks:

defining a list of aspects significant for multi-unit effects (hazards, common systems and buildings, mutual impact, etc.) and developing an approach to their consideration in the models of Level 1 and 2 PSA;

studying results of PSA for certain aspects to determine significant risk contributors related to multi-unit features of the site.

The SSTC NRS focuses its studies on the Rivne NPP site (Figure 1) having some specific features that are interesting from the viewpoint of assessment within a multi-unit PSA, in particular:

units of two different designs are located at the site, namely: Units 1 and 2 with WWER-440/213 and Units 3 and 4 with WWER-1000/320;

Units 1 and 2 have several interconnections, for example: common central hall and some common equipment in it;

in-house cross sectional power supply of the power units is provided;

generated electricity of the site is supplied by common lines of 330 kV and 750 kV switchyard energy system.

As the first step of the study, interconnections between the units were analysed and multi-unit aspects of the site were determined based on analysis of the safety justification and operational documents for Units 1-4 and the site as a whole. Based on the determined multi-unit aspects, Rivne Units 1 and 2 were selected for further study, which included the following steps:

selection of a representative multi-unit initiating event to perform core damage frequency (CDF) estimation (initiating event T8 «Loss of Essential Service Water System» was selected);

integration of Level 1 and Level 2 PSA models of Units 1 and 2 into one model;

modification of Level 1 and Level 2 PSA models to consider interconnections of Units 1 and 2;

estimation of the multi-unit CDF and early release frequency (ERF) for the selected initiating event.

The CDF and ERF were calculated in relation to internal initiating events in reactor full power operation in order to verify the PSA models regarding internal initiating events for reactor full power operation. Within the analysis, the existing PSA model of Unit 2 was corrected for further combination of the models of Units 1 and 2 and estimation of the multi-unit CDF/ERF. The preliminary results of multi-unit CDF and ERF estimation showed a significant decrease in these parameters.

At present, the MUPSA team, including the SSTC NRS, is preparing the IAEA TECDOC «Probabilistic Safety Assessment Benchmarks for Multi-Unit/ Multi-Reactor Sites». The TECDOC provisions and experience gained in the MUPSA project will be used by the SSTC NRS in a regulatory review of the PSA studies for Ukrainian NPPs.

CRP J15002 «Effective Use of Dose Projection Tools in the Preparedness and Response to Nuclear and Radiological Emergencies» (2019 – 2022)

IAEA CRP J15002 is implemented by experts in emergency preparedness and response representing the world's leading institutions including researchers from France, China, Canada, US, Spain and Ukraine. It is one of the projects addressing emergency preparedness and response issues whose main aims and outcomes lie in the practical domain.

The dose projection tools are a valuable instrument for the decision-making. Every update to the existing codes and instruments enhances their capacities and strengthens the reliability and robustness of the output data.

The project is focused on the dose projection as the most solid ground for making decisions on protective measures in case of a major accident. In particular, the research component of the project consists in study of models used in practice and understanding their limitations. Importantly, the project resorts to the benchmarking, which is a valuable instrument often referred to as «the most honest measure of

Figure 1 – Rivne NPP site

success» due to its ability to quantify the performance of codes and related methodologies, and to identify the room for improvement. Having certain experience in benchmarking of dose projection tools, the SSTC NRS joined the work of IAEA IEC team under this Project.

This project provides responsible institutions with a platform for cooperation and exchange of ideas and, therefore, contributes tremendously to the continuous improvement in the efficiency of the modelling tools.

One of the SSTC NRS functions in the support of the national nuclear regulator in emergency preparedness and response is fulfilled through participation of SSTC NRS experts in the SNRIU Information and Emergency Center (hereinafter – IEC). Although the dose projection tools provide the fastest and the most available data to support the decision-making, the real measurements on the affected site, in the vicinity or on the contaminated territories along the radioactive plume provide more reliable and comprehensive information. However, taking into consideration the time constraints and the large territories to be monitored, it is important that the resources for real-time emergency monitoring are channelled to support of the IEC, and not just for the collection of random measurement data. Such synergy can be achieved through the joint use of a decision support system and a mobile laboratory during a nuclear accident.

This scientific goal pursued by the SSTC NRS gave the name to the research carried out by its experts under the contract with the IAEA in the framework of CRP J15002. The necessity to consolidate the available resources to enhance the efficiency of dose projection by the IEC has been a matter of utmost urgency to the SNRIU and SSTC NRS with regard to the wildfires regularly breaking out on the territories affected by the Chornobyl accident, placing Ukraine among the few countries who systematically face the need to mount emergency activities in response to a real radiological threat [3], [4]. Although the wildfires only lead to the re-distribution of radioactive contamination in the environment and thus do not require full-scale involvement of the IEC, the proximity of the Chornobyl exclusion zone to Kyiv makes these events a subject of significant public concern (Figure 2).

Two basic instruments used by the SNRIU/SSTC NRS in support of emergency preparedness and response during wildfires are the RanidSONNI mobile laboratory and the JRODOS European decision support system. It was noted that the simulation used to determine location and time of air sampling and field measurements improved the efficiency of the real-time monitoring, and the measured and modelled concentrations converge with sufficient accuracy [5] (Figure 3).

Taking into consideration the larger (and faster to sample and measure) airborne contamination, which might be expected during a nuclear accident, the idea of the joint use of the abovementioned tools seems to be very promising. However, to reach perfect and effective synchronization, a set of procedures needs to be developed and practically tested.

The first year of SSTC NRS work under the project was focused on the capability analysis of an «ideal» emergency response laboratory vehicle, and on the definition of a unified list of parameters to link the stages of modelling with the real-time measurements. The optimal configuration of the mobile laboratory would be a shielded van (or a trailer) with increased travel capability, a reliable wireless communication channel for the quick exchange of information with the control center operated by environmental monitoring experts

Figure 2 – SSTC NRS emergency crew performing radiological survey in Kyiv after a storm during wildfires in the Chornobyl Exclusion Zone (April 2020)

Figure 3 – RanidSONNI mobile laboratory arrived at the recommended location for aerosol sampling during wildfires in the Chornobyl Exclusion Zone (April 2020)

with an adequate level of proficiency in use of personal protective equipment, environmental sampling equipment, and knowledge of laboratory techniques, equipped with the certain measurement tools capable of providing measurements necessary to support the modelling according to the chosen parameters. With minor and generally amendable weaknesses, the RanidSONNI mobile laboratory meets the requirements of the IEC expert operating JRODOS.

The current year is devoted to developing the response action timeline for the mobile laboratory alongside with outlining the radiation protection measures of the emergency crew. After the field testing (planned for the last year of the project), these timelines will become the basis for methodological recommendations on the joint use of the mobile monitoring tool and the decision-support system in case of a nuclear emergency at a light-water reactor. Containing, among the procedural arrangements, the basic requirements, principles and recommendations for such a consolidation, this document will be universal and applicable to any configuration of the mobile laboratory and any dose projection tool and thus will enhance the SNRIU capabilities in emergency preparedness and response. This research may also contribute to strengthening of IAEA-TECDOC-1092 «Generic Procedures for Monitoring in a Nuclear or Radiological Emergency» in the light of evolution of real-time tools for the projection of radiological consequences.

CRP J46002 «Developing a Phenomena Identification and Ranking Table (PIRT) and a Validation Matrix, and Performing a Benchmark for In-Vessel Melt Retention (IVMR)» (2020 – 2024)

After the Fukushima-Daichi accident in 2011, the practices and approaches to NPP design and operational safety were re-evaluated worldwide, resulting in the development of more stringent requirements that are reflected in new or revised IAEA and WENRA documents [6], [7] and have been adopted (or are being adopted) in national regulations. In particular, the concept of design extension conditions (DEC) with or without core melting has been introduced and needs to be addressed in the design of new NPPs by incorporation of dedicated safety features which are capable of preventing or mitigating the events considered in DEC. For existing NPPs, these requirements shall be used to identify reasonably practicable safety improvements that can be implemented to further enhance safety of NPP operation (para. 1.3 [6], F1.2 [7]).

For DEC with core melting, the main plant objective is to preserve integrity of the containment as the last safety barrier preventing uncontrolled radioactive release to the environment. In particular, para. 5.30 of SSR-2/1 [6] requires that the containment and its safety features shall be able to withstand extreme

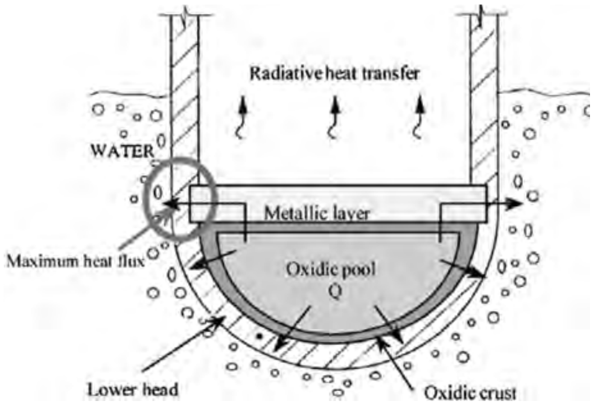

Figure 4 – In-vessel melt retention [8]

scenarios that include, among other things, melting of the reactor core.

One of the accident management strategies that allows eliminating a number of potential threats to the containment integrity after melting of the reactor core is the in-vessel melt retention (IVMR) (Figure 4).

The strategy is based on flooding of the reactor cavity and establishing cooling of the reactor pressure vessel (RPV) from the outside (by coolant heating and evaporation), thus enabling the heat removal from the molten corium relocated to the reactor lower plenum in order to avoid RPV failure. If successful, the strategy eliminates the potential of ex-vessel steam explosions, containment basemat melt-through, and generation of significant amounts of hydrogen from molten corium-concrete interactions at the ex-vessel severe accident progression phase.

The idea of IVMR strategy was proposed and implemented at the Loviisa WWER-440 NPP in Finland and was further developed and incorporated to other NPP designs, e.g., Westinghouse AP600 and AP1000 NPP, Korean APR-1400 (with combined in-vessel and ex-vessel cooling) and others [8, ch.6.3.2].

Regardless of the progress achieved in developing the methodology for evaluation of IVMR, as well as in experimental and analytical activities, significant interest exists within the community of designers and analysts to the various aspects of the strategy phenomenology and effectiveness justification [9], especially as applied to medium- and high-power reactors. Considering this, in 2020 IAEA commenced a new coordinated research project «Developing a Phenomena Identification and Ranking Table (PIRT) and a Validation Matrix, and Performing a Benchmark for In-Vessel Melt Retention (J46002)» with the main objective of harmonizing the international understanding of scientific and technological bases underpinning the crucial parts of safety demonstration of the IVMR strategy [10].

The CRP is planned to be performed within the following four years and consists of four main tasks [10], including:

development of PIRT identifying and ranking the phenomena relevant for IVMR strategy;

development of a validation matrix that provides a link between the IVMR phenomena, relevant test facilities and experiments (including separate-effect tests and integral tests), and selection of high-quality experimental data that can be used for validation of computer code models for simulation of the IVMR strategy;

benchmark involving code-to-code comparison and comparison with experimental data on individual IVMR phenomena selected based on PIRT. The objective of the benchmark is to characterize the capabilities of currently implemented code models to adequately simulate the phenomena of interest as well as to provide the input for further improvement of computer code models and uncertainty reduction;

analytical benchmark of a comprehensive IVMR scenario to demonstrate improvements in the models resulting from the individual phenomena benchmark.

Under this CRP, the IAEA joins scientists and researchers from Canada, China, France, Germany, Korea and other countries, and provides a platform facilitating interactions among experts on the phenomenological and methodological aspects of IVMR strategy evaluation.

In the framework of this project, the main SSTC NRS effort will be focused on performing computer simulations within the CRP benchmark activities including the individual phenomena benchmark and analytical benchmark of the comprehensive scenario. For these purposes, the MELCOR code will be used. The results of SSTC NRS simulations will be compared with the ones obtained by other project participants and with experimental data (provided that these results are made available within CRP) with the objective to evaluate the applicability of the code models and of simulation techniques used for modelling the IVMR.

This effort will enhance the SSTC NRS understanding of IVMR phenomenology, methods and approaches that are used worldwide for the safety demonstration of IVMR strategy and will extend the scientific knowledge and background necessary for performing the main SSTC NRS objective of providing the technical support to the Ukrainian regulatory authority. Participation in the project becomes of particular importance in the light of the operating organization plans to re-initiate construction of Khmelnitsky NPP Units 3 and 4, where IVMR is being considered as the main component of severe accident management strategy.

CRP T13018 Spent Fuel Characterization (2020 – 2024)

The characterization of spent fuel is an important component of safety substantiation in various steps of spent fuel management, and the project makes an emphasis on the steps of spent fuel storage, transport and conditioning for disposal. The objective of this CRP is to support sharing information among all countries that deal with nuclear fuel regarding assessment of its characteristics during all stages of fuel management. This objective is achieved by gathering information regarding the approaches to characterization that have been taken and are being developed for the various steps of spent fuel management (SFM), including the validation of models, techniques and procedures. The leading institutes from Finland, Lithuania, Mexico, Netherlands, Republic of Korea, Romania, Slovenia, Spain, Sweden, Switzerland, UK and Ukraine take part in the project. Different types of techniques for analysis of fuel characteristics are provided such as destructive, non-destructive and modelling. Of all the proposals submitted to the IAEA, 11 research agreements and 7 research contracts were selected and accepted. Among the accepted proposals, four have an experimental basis, 11 have a modelling basis and three involve both aspects. Research deals with fuel types such as AGR, BWR, CANDU, PWR, RBMK, and WWER accounting for a worldwide variety of operating nuclear facilities [11].

The SSTC NRS will contribute to the project results by sharing information among the participants on the WWER-1000 fuel isotopic inventory and source term after in-core irradiation. The information will be based on the spent fuel characterization with account of associated nuclear data uncertainties and using validated and best-estimate computer codes, NPP realistic burnup data, and modern nuclear data libraries.

An essential safety factor for long-term (50 years and more) storage of spent fuel assemblies is the availability of information both regarding the integral parameters of spent nuclear fuel (SNF) and the distribution of its local characteristics. Significant non-uniformities in the distribution of local characteristics might lead to accelerated local degradation of SNF elements and consequently result in significant limitation of the feasibility, conditions and terms of its storage.

As usual practice, the SNF characteristics (isotopic composition, residual energy release, etc.) are defined for a fuel assembly as averaged values with account of averaged operating parameters. Nevertheless, it is well known that a number of operational parameters may reveal significant heterogeneities in both axial and radial directions within a fuel assembly. Such operational parameters include the coolant temperature and density, distribution of energy release power, neutron flux and others. Local non-uniformities and fluctuations in operational parameters lead to local changes in the SNF characteristics. This might lead to a local excess of the allowed limit values of the SNF characteristics and, as a result, to SNF local damage, which is unacceptable for the storage safety.

Change of fissile isotopes in the axial direction of a fuel assembly can serve as a good example of how non-uniformities of such operational parameters affect fuel characteristic. Calculations of isotopic change with different moderator densities (Figure 1 presents the results for three density values: g_{mod} =0.753 g/cm^3 being typical for the lower reactor core part, g_{mod}=0.716 g/cm^3 for the middle core part and g_{mod}=0.685/cm^3 for the upper core part) show that deviations of the neutron energy spectra due to different moderator densities can give a valuable difference of nuclide concentration for the same burnup (up to 10% for ^{239}Pu, Figure 5) [12]. Moreover, significant non-uniformity of fuel characteristics is caused by burnup redistribution over the period of fuel operation in the reactor core in both the axial and radial direction. Burnup distribution in the radial direction for a standard WWER-1000 fuel assembly after 4-year operation is presented in Figure 6, indicating 15% burnup distortion for different fuel pins within the same assembly.

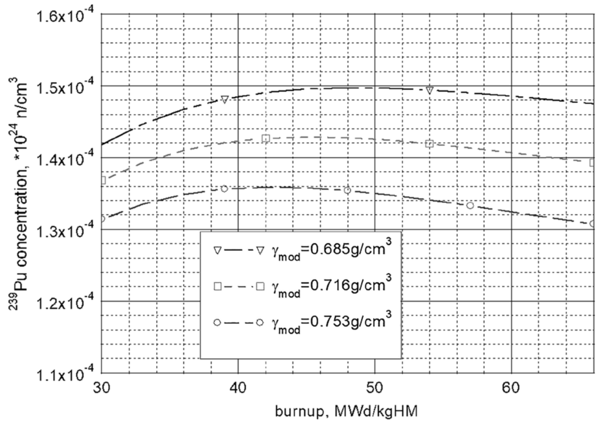

Figure 5 – Change of ^{239}Pu concentration during fuel burnup

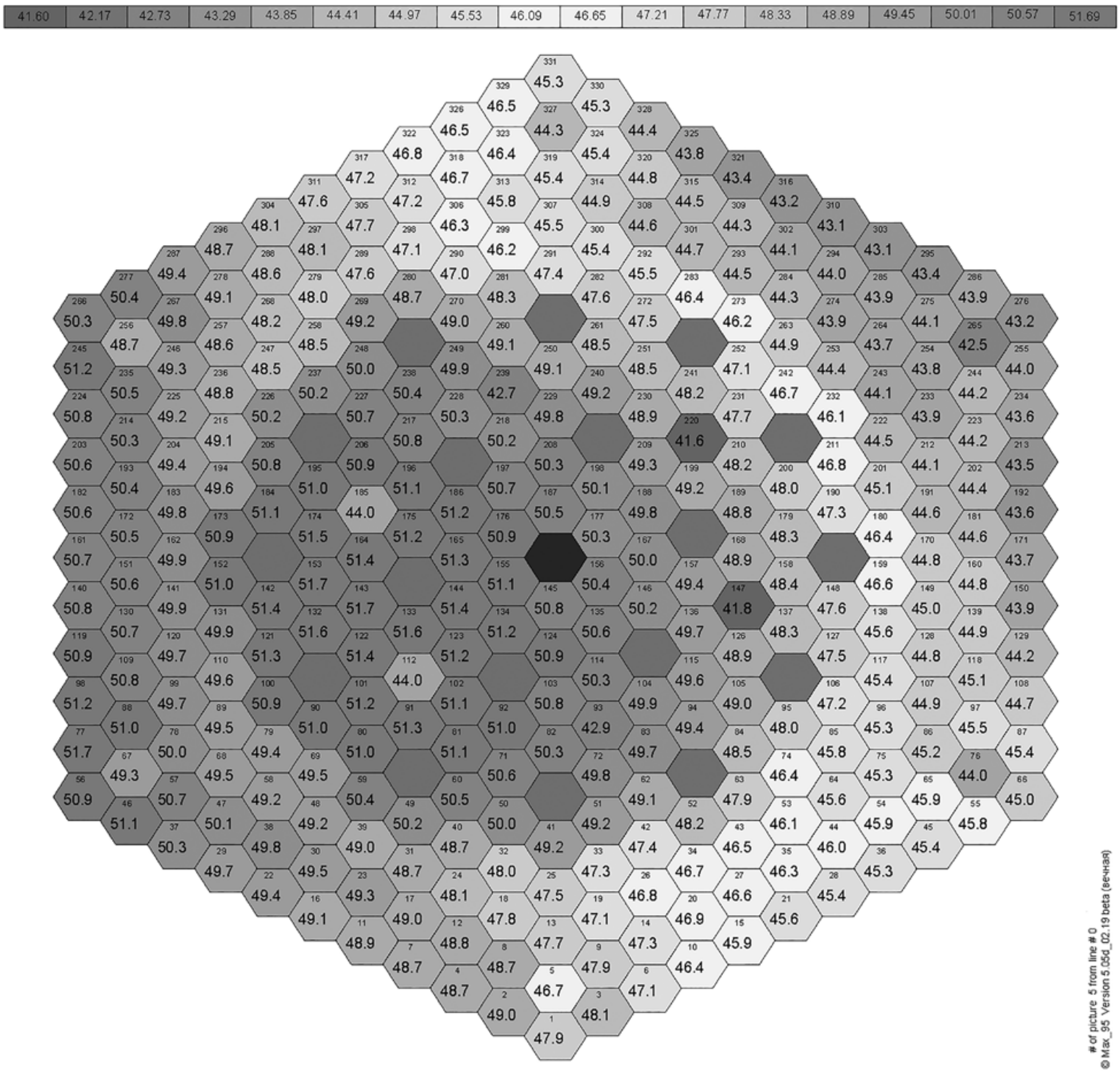

Figure 6 – WWER-1000 FA burnup (MW· d/kgU) distribution after 4-year operation

Therefore, the specific objective of the research project proposed by the SSTC NRS is to analyse the impact of such possible local changes in operational parameters on the distribution of local SNF characteristics and on the integral values of SNF characteristics. First, this relates to characteristics of spent nuclear fuel such as residual energy release, activity, distribution of fissile isotopes, etc.

The study will be performed for the selected representative types of fuel assemblies used in WWER-1000 reactors of Ukrainian NPPs (e.g., for fuel assemblies produced by TVEL in Russia and Westinghouse in the USA [13]) by numerical simulation using best-estimate models for the SCALE software package. In the frame of this CRP, the SSTC NRS is performing analysis of the characteristics of various types of fuel that is in operation and storage at Ukrainian NPPs (enrichment and its distribution; presence, quantity and distribution of burnable absorbers, uranium mass per fuel assembly; structural materials; allowable burnup depth; allowable uneven distribution of energy release and temperature, etc.) with the aim to select one/two representative types of fuel assemblies for further modelling. After the development of computer models using first at all the SCALE software package, local irregularities associated with the fuel fabrication technology and operating conditions that are typical for fuel assemblies used in WWER-1000 reactors at Ukrainian NPPs will be analysed.

Sharing results of the performed analysis with other partners will contribute to:

exchange of information on the state-of-the-art methods, calculation techniques and codes for spent fuel characterization at various steps of spent fuel management after the end of nuclear fuel operation in the reactor core;

improving relevant knowledge on WWER-1000 spent fuel characteristics and their evolution until disposal;

identifying the potential for further cooperation among the research organisations dealing with similar analysis and other reactor types.

The analysis performed in the framework of the project will enhance the SSTC NRS capabilities in activities related to technical review of materials on safety substantiation of spent fuel management from all 15 units of four Ukrainian NPPs (13 units with WWER-1000 reactors and 2 units with WWER-440 reactors) that are in operation now. The SFM activities will mostly address storage of SNF after initial cooling in the spent fuel pool from six units of the Zaporizhzhya NPP at the on-site dry interim spent fuel storage facility and storage of fuel from other power units in a separate dry interim storage facility that is under construction now.

Conclusions

The SSTC NRS considers its expanding experience of participation in the IAEA coordinated research activities as being very positive. Over the last seven years, the SSTC NRS became a partner organisation for the IAEA in five Coordinated Research Projects. An application has recently been submitted to the IAEA for participation in a new CRP related to water resource management in mining areas.

The main incentives for the SSTC NRS involvement in the international cooperation organized, supported and coordinated by the IAEA are as follows:

the IAEA mechanism of CRPs demonstrates to be a well-organised and efficient platform facilitating research cooperation of organisations from the Member States,

the role of a CRP participant enables access to the state-of-the-art international thematic research, opportunities for exchanging technical data, information, experience and knowledge in the areas that are of high practical interest for SSTC NRS and national nuclear regulator,

CRPs provide a solid basis for cooperation of partners with different experience, as well as for professional development of young researchers and engineers.

As a feedback from the SSTC NRS participation in CRPs, the scientific and technical potential of the enterprise is increasing in various areas. This leads to strengthening the SSTC NRS professional competences and to expanding the spectrum of topics that could be the subject of in-depth studies to support regulation of nuclear and radiation safety.

References

1. Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants for protecting people and the environment. Specific Safety Guide No. SSG-3. IAEA, Vienna, 2010.

2. Attributes of Full Scope Level 1 Probabilistic Safety Assessment (PSA) for Applications in Nuclear Power Plants, IAEA-TECDOC-1804, IAEA, Vienna (2016).

3. Environics. (2020, April 16). *RanidSONNI Used to Survey Kyiv Suburban Areas Due to Chernobyl Wildfires.* Retrieved from: https://environics.fi/news/ranidsonni-used-to-survey-kyiv-suburban-areas-due-to-chernobyl-wildfires/.

4. Environics. (2015, November 16). *RanidSONNI was used to confirm radiation safety in Kiev after fires at Chernobyl NPP area.* Retrieved from: https://environics.fi/news/ranidsonni-was-used-to-confirm-radiation-safety-in-kiev-after-fires-at-chernobyl-npp-area/.

5. Bogorad, V., Bielov, Y., Kyrylenko, Y., Lytvynska, T., Poludnenko, V., & Slepchenko, O. (2018). Combination of RanidSONNI Mobile Laboratory Devices and Rodos DSS computer Technologies to Forecast Consequences of Fires in the ChNPP Exclusion Zone. *Nuclear and Radiation Safety*, 3(79), 10-15. doi: 10.32918/nrs.2018.3(79).02.

6. Safety of Nuclear Power Plants: Design. Specific Safety Requirements. No. SSR-2/1 (Rev.1). IAEA, Vienna (2016).

7. WENRA Safety Reference Levels for Existing Reactors. Update In Relation To Lessons Learned From Tepco Fukushima Dai-Ichi Accident. WENRA RHWG Report. 24 September, 2014.

8. Sehgal B. R. (2012) *Nuclear Safety in Light Water Reactors. Severe Accident Phenomenology.* First Edition. 740 p.

9. IAEA. (2020, January 17). *New CRP: Developing a Phenomena Identification and Ranking Table (PIRT) and a Validation Matrix, and Performing a Benchmark for In-Vessel Melt Retention (J46002).* Retrieved from: https://www.iaea.org/newscenter/news/new-crp-developing-a-phenomena-identification-and-ranking-table-pirt-and-a-validation-matrix-and-performing-a-benchmark-for-in-vessel-melt-retention-j46002).

10. Call for Research Proposals for participation in the New Coordinated Research Project (CRP) sponsored by the International Atomic Energy Agency (IAEA) «Developing a phenomena identification and ranking table (PIRT) and a validation matrix, and performing a benchmark for In-Vessel Melt Retention» J46002.

11. Spent Fuel Performance Assessment and Research Final Report of a Coordinated Research Project on Spent Fuel Performance Assessment and Research (SPAR-III) 2009–2014. IAEA-TECDOC-1771, IAEA, Vienna (2015). 220 p.

12. Bilodid, Y., Ovdiienko, I., Mittag, S., Kuchin, A., Khalimonchuk, V., Ieremenko, M. (2012). Assessment of spectral history influence on PWR and WWER core. *Kerntechnik,* 77(4), 278–285. doi: 10.3139/124.110254.

13. Kovbasenko Y. (2016). Comparative Analysis of VVER-1000 Westinghouse and TVEL Spent Fuel Capability. *Universal Journal of Physics and Application*, 10(4), 105 – 109. doi: 10.13189/ujpa.2016.100401.

Зміцнення науково-технічного потенціалу ДНТЦ ЯРБ через участь в координованих дослідницьких проєктах МАГАТЕ

Балашевська Ю. В., Гуменюк Д. В., Овдієнко Ю. М., Печериця О. В., Шевченко І. А., Єсипенко Ю. В., Жабін О. І.

Державне підприємство «Державний науково-технічний центр з ядерної та радіаційної безпеки», м. Київ, Україна

Державне підприємство «Державний науково-технічний центр з ядерної та радіаційної безпеки» (ДНТЦ ЯРБ), підприємство з 29-річним досвідом науково-технічної підтримки національного регулятора з ядерної та радіаційної безпеки (Держатомрегулювання), бере активну участь у міжнародній дослідницькій діяльності. Участь у дослідженнях, які координує МАГАТЕ, є одним із пріоритетів ДНТЦ ЯРБ. У період 2018 – 2020 років МАГАТЕ прийняло чотири пропозиції Центру щодо участі у відповідних координованих науково-дослідних проєктах. Ці проєкти присвячені науково-технічним питанням у різних сферах, зокрема: 1) проведення імовірнісної оцінки безпеки для багатоблокових/багатореакторних майданчиків; 2) використання інструментів прогнозування дози під час забезпечення готовності та реагування на ядерні та радіологічні надзвичайні ситуації; 3) аналіз явищ, пов'язаних із утриманням розплаву всередині корпусу реактора; 4) характеризація відпрацьованого ядерного палива.

Стаття містить короткий огляд зазначених проєктів з визначенням наукового внеску ДНТЦ ЯРБ (участь у порівняльних розрахунках (бенчмаркінгах), під час розробки методичних документів з проведення етапів досліджень та технічних документів (TECDOC) МАГАТЕ, з висвітленням кращих практик та здобутків досліджень, виконаних міжнародними командами науковців).

Ключові слова: багатоблоковий (багатореакторний) майданчик АЕС, інструменти прогнозування дози, координовані дослідницькі проєкти МАГАТЕ, утримання розплаву всередині корпусу реактора, характеризація відпрацьованого палива.

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