JRC ACTIVITIES IN NUCLEAR SAFETY

by

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Nuclear energy is today the largest single source of carbon free and base-load electricity in Europe. While highlighting its important role in the overall energy mix, it is necessary to address sustainability, safety, and security concerns, in particular nuclear safety and nuclear waste management issues, which influence the public acceptance of nuclear energy. The present paper describes the Joint Research Centre activities in support to the EU nuclear safety policy. It describes the Joint Research Centre role in the EU institutional context, identifies the various customers to which the Joint Research Centre delivers its services, and provides some results of the Joint Research Centre scientific work inherent to nuclear safety.

Key words: energy, nuclear energy, nuclear safety, European Commission, JRC

INTRODUCTION

Sustainability, security of supply and competitiveness are the goals of the EU energy policy. Nuclear energy has an important role in the overall energy mix: today it is the largest single source of carbon free and base-load electricity in Europe. Europe has the largest number of commercial nuclear power stations in the world, and the nuclear industry is leading the world, thanks to its technological capabilities. However, by 2005, more than 70% of such power plants had passed their 20-year life span, with almost 30% more than 30 years old. As Europe's 150 nuclear power reactors grow older, maintaining high safety levels is a key issue for industry and policymakers.

The renewed European and global interest in nuclear energy, the Nuclear Renaissance, is due to the fact that nuclear energy is a major contributor in the fight against the climate change and in the enhancement of the security of energy supply. While highlighting the important role of nuclear in the overall energy mix, it is necessary to address nuclear safety concerns and nuclear waste management, which are all important elements for public acceptance of nuclear energy. Since the establishment of the Euratom Treaty, nuclear safety, and the radiological protection of the public have been main concerns of the European Community, and are issues that have received importance within the enlargement process.

By tackling these issues, nuclear safety research is addressing the long-term safe operation of both Western and Russian type of nuclear power plants. To this end, advanced and refined safety assessment methodologies and corresponding analytical tools have been and have to be extended and validated. Targeted experimental investigations are enabling the validation and verification of the safety assessment tools and the deeper understanding of the underlying physical phenomena and processes.

On the other hand, activities with regard to the safety of nuclear fuel concentrate on the prevention and mitigation of the consequences of accidents. The two main aspects in this research are: the mechanical integrity of the fuel assemblies during the reactor lifetime, and fuel response to accident conditions and severe accident conditions. The studies have also to reflect on the new reactor strategies presently considered worldwide, such as the Generation IV International Forum (GIF), inspired by a comprehensive

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assessment including public concerns, such as improved safety, reduced wastes and improved resistance to proliferation.

The European Commission has worked for many years with the support of expert groups on the nuclear safety issues and, in particular, on the progressive harmonisation of safety requirements and practices to ensure the highest standards of nuclear safety. In particular, the Joint Research Centre (JRC) has stimulated and carried out at EU level research together with international organisations involved in nuclear research and activities.

THE JOINT RESEARCH CENTRE OF THE EUROPEAN COMMISSION

The JRC [1] was initially established by the Euratom Treaty and has since become a leading institute of nuclear research in Europe, whose role is to be a European independent reference centre of science and technology in the areas of its specific competence [2]; in particular, the JRC has led fifteen years of network collaboration between key European players in research and development (R&D) on ageing nuclear power plant safety.

The JRC is a Directorate-General (DG) of the European Commission under the responsibility of Janez Potočnik, the EU Commissioner for Research. DG JRC is made of seven institutes, located in five separated sites: Belgium, Germany, Italy, Spain, and The Netherlands; the headquarters are located in Brussels. JRC has a broad spectrum of customers, both within the European institution and in EU member states.

Within the EU institutions, the JRC customers are other Commission services, in particular those DGs which are responsible for EU sectoral policies, such as energy, environment, health, and consumer protection, agriculture, and fisheries. The customer DGs participate in the drafting of the JRC annual work-programme by putting forward their priority needs of scientific support for the policies under their responsibility [3]. Furthermore, other institutional customers are within the European Parliament (EP), which shares legislative power over many EU policy areas with the Council. Among others, the JRC collaborates with STOA, the office for the assessment of scientific and technological policy options of the EP.

Other important customers are international organisations, mainly IAEA, OECD, ISTC, and the Scientific Community at large. The JRC has many other customers and stakeholders in the EU member states and in the countries associated with the Seventh Framework Programme for Research and Technological Development (FP7) [4]; they are represented in the JRC Board of Governors.

For a programmatic point of view, the main strategic objectives of the JRC, in its main areas of involvement, are presented by thematic strategis*, which are living documents bringing coherence to the specific contributions made by the institutes. At the institute level, in the JRC institutes the work-programme is implemented through projects, which are also called "actions".

JRC ACTIVITIES IN THE FIELD OF NUCLEAR SAFETY

Nuclear safety is not only a national issue. Nuclear accidents may impact territories covering many EU member states (or other states), and may influence the public opinion and perception on a global scale. Hence the need to tackle the nuclear safety concerns through integrated approaches and broad policies.

The nuclear activities of the JRC aim to support related Community policies and specific Euratom Treaty obligations. These activities are focused in areas and on topics where Community involvement is appropriate, where JRC action is justified by the cross-border dimension of nuclear safety and security, and/or by public concerns, and where the European identity of JRC brings the added value. An example of support to the Community policies is the scientific and technical support provided to the EC DG EuropeAid (AIDCO), with respect to the implementation of TACIS and also PHARE nuclear safety programmes. Moreover, JRC is supporting DG Enlargement (ELARG) with respect to the implementation of two projects for the Vinča Institute of Nuclear Sciences of the Republic of Serbia. The first project is the "Preparation for and transportation of spent nuclear fuel (SNF) from the Vinča institute of the Republic of Serbia (RS) to the Russian Federation (RF) – project No. 1 of 5" (EU contribution 100% – 4 430 000 Euros). The second project is for supplying "Equipment for the radioactive waste processing facility at the Vinča Institute – project No. 2 of 5" (EU contribution 100% – 1 040 000 Euros).

The JRC research on nuclear safety is carried out mainly at the Institute for Energy (IE) [5] in the Netherlands, at the Institute for Transuranium Elements (ITU) [6] in Germany. The research activities cover both the safety of the reactors and the safety of the nuclear fuel itself, and are in three main areas:

– safety of nuclear installations,
– nuclear fuel safety in power reactors operating in the EU, and
– safe operation of advanced nuclear energy systems.

* The JRC thematic strategies are: energy, climate change, environ ment & health, sustainable agriculture, econometrics & statistics, security, nanothechnologies, biotechnology, chemicals, food & feed, natural resources, sustainable transport, information society technology, development co-operation, fisheries & maritime.

Nuclear safety activities at the JRC Institute for Energy

The following actions are ongoing at the Institute for Energy.

(1) NUSAC: Nuclear safety clearinghouse

Several international forums, amongst which the Conference on Improving Nuclear Safety through Operating Experience Feedback that was held on the 29-31 of May 2006 in Cologne, Germany, have suggested that EU countries may benefit from coordinating their efforts at the Community level to improve the operational experience feedback (OEF) process. Recognizing the importance of exploiting synergies for tackling nuclear safety issues, it was suggested, and later requested by some EU member states (MS), that JRC plays a central role in establishing and running a European Clearinghouse for Operational Experience Feedback, for the benefit of all MS, see fig. 1. It was decided to use well established JRC means and capabilities, as well as available JRC and EU expertise in the field, in order to promote better cooperation, the synergistic use of the national resources of the MS, and strengthening the EU capabilities for operational experience analyses and dissemination of the lessons learnt.

The action provides an integrated approach to the research needed to enhance the Community capabilities for the assessment of operational experience of EU nuclear power plants, and promote the development of tools for the improved application of the lessons learnt. The main strategic goals of the European Clearinghouse for Operational Experience Feedback (OEP) to be established will be: (a) the improvement of EU NPP safety through enhanced cooperation between licensees, regulatory authorities and research institutes, (b) the establishment of European best practices for the assessment of NPP operational events through the use of state-of-the-art methods, computer-aides assessment tools, and information gathered from different national and international sources (*e. g.* EU Regulatory Authority event reporting systems, NRC Operational Experience Clearinghouse, Incident Reporting System jointly operated by IAEA and OECD/NEA), and (c) the support to the long-term EU policy needs on OEF.

(2) SONIS: Safe operation of nuclear installations

Nuclear safety of the operating installations is more and more subject to optimisation in order to meet the new challenges posed by the new socio-economical framework where the nuclear plants have to operate; emerging issues are linked to the challenges of market liberalization and the long-term safe operation of the plants.

According to the IAEA Requirements for Operation of Nuclear Power Plants, the identified priorities are: maintenance, testing, surveillance and inspection (MS&I) programs, engineering programs supporting operation, operating procedures, and human reliability aspects (including, among others, human factors, safety culture, organisational culture, organisational design, operation feedback). The optimisation of these programs requires the large effort of development of new techniques and models, and the availability of

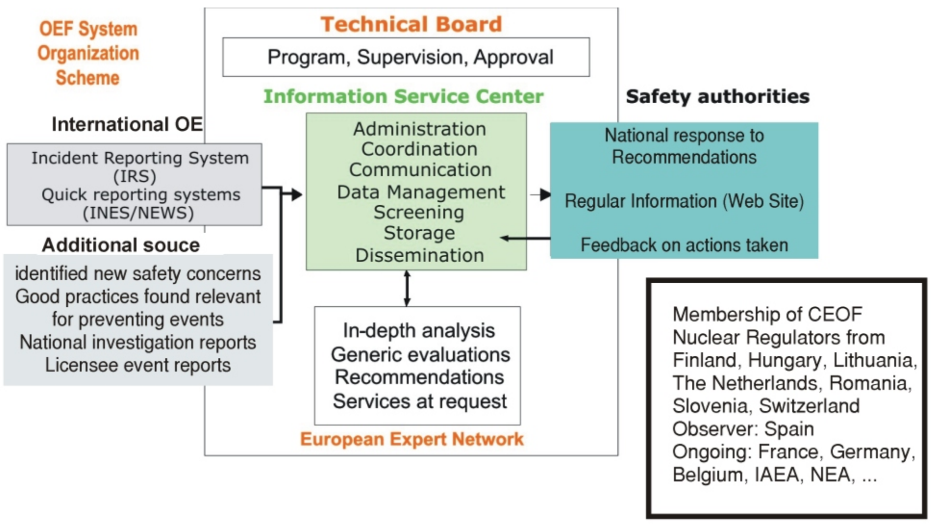


Figure 1. Nuclear safety European clearinghouse for operational experience feedback at JRC (as proposed by J. Laaksonen and J. J. van Binnebeck to WENRA for november 2007 meeting)

component data, well assessed probabilistic techniques, complicated cases studies. Such effort cannot be managed at the sole country level and needs the benefits of an integrated European approach for achieving results in a realistic time-span.

The JRC action aims at facing technical and organisational issues related to the safe operation of the existing European nuclear facilities in an integrated research approach [7-10]. The action focuses on the following strategic goals: (a) support the long-term EU policy needs on the nuclear safety and security of the existing installations, (b) provide a basis for harmonisation of European best practices and approaches regarding the operational safety of nuclear installations, and (c) integrate the research efforts with the ongoing efforts implemented by the nuclear utilities and plant designers.

(3) SAFELIFE: Safety of ageing components in nuclear power plants

In the last two decades, the Commission has been coordinating major networks on the ageing of materials in nuclear power plants (AMES), on inspection and qualification (ENIQ), for evaluating structural integrity of components (NESC), on application of neutron diffraction techniques (NET), on the assessment of core internals (AMALIA), and on the safety of Eastern European type nuclear facilities (SENUF). These are part of the JRC's SAFELIFE project on the safety of ageing nuclear power plants, which addresses issues such as the upgrading safety of Soviet-era nuclear reactors in Eastern Europe, verifying the capability of ageing nuclear facilities to withstand accidents, and preventing cracks and leaks, see fig. 2.

The action gathers European R&D efforts on ageing and degradation issues for nuclear power plant components to support safe and economic long-term operation of the EU current fleet of over 150 reactors as well to ensure that new designs incorporate the lessons-learned and best technology from the existing plant life management programmes. SAFELIFE helps underpinning the Commission's knowledge base on plant life management issues, with a major focus on the structural safety of key components. It uses the JRC's European institutional status to promote better integration and exploitation of R&D efforts in this area by organising its own networked activities, as well as playing a major role in the Nuclear Plant Life Prediction (NULIFE) network of excellence.

SAFELIFE focuses on establishing best-practices for deterministic and risk-informed methods for assessing structural safety of key components in both western and Russian nuclear power plant designs, as a part of an integrated approach to life management of ageing nuclear power plants. It takes advantage of the JRC/IE's general competence in plant life management issues, in particular materials degradation, structural mechanics, condition monitoring techniques, neutron measurement methods, residual stress analysis and risk-based approaches.

The action coordinates network and training activities as a part of the realisation of the European Research Area, including in particular its leading role in the NULIFE network of excellence. NULIFE and existing networks also represent the main means for supporting the nuclear safety policies of the member states.

SAFELIFE develops and coordinates activities in its field of competence for policy DGs of the European Commission. It also supports relevant international projects organised by the IAEA and the OECD NEA, and has a continuous effort to integrate experts and organisations from new member states and candidate countries in its activities. Links to research organisations in Russia and ex-Soviet states operating nuclear power plants are realised via the ISTC Contact Expert Group on Plant Life Management (PLIM).

(4) SAFETY-INNO: Safety of innovative reactor design

In the European vision for a medium to long-term development of nuclear energy, innovative reactors offer numerous advantages ranging from minimised waste and resistance to proliferation, enhanced safety and reliability, sustainability, and competitiveness. Ten countries, including France and Switzerland, as well as the EU, represented by Euratom and with the JRC as implementing agent, are working together within the Generation IV International Forum (GIF) to perform pre-competitive R&D on key technologies likely to be implemented in future nuclear systems. SAFETY-INNO is one of the contributing JRC actions.

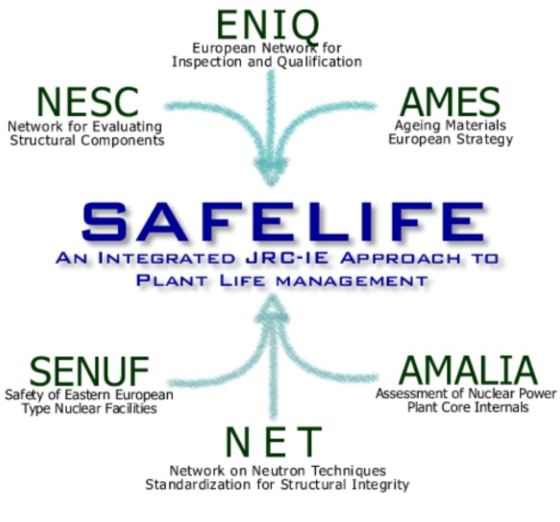


Figure 2. The action SAFELIFE and its networks

The action answers to the need for thoroughly assessing the technical evolution of various innovative nuclear power systems against the specific needs for EU countries. The goal is to provide the Community with the information required for implementing its responsibilities if some of the concepts selected by GIF are considered suited for industrial deployment in Europe. This implies participation both in the technical GIF projects and in various coordination bodies pursuing new R&D results and improved system specifications.

The technical JRC contributions to these projects go through both institutional actions and RTD-funded projects and are meant to cover identified key feasibility issues of the GIF concepts such as fuel and material testing, and safety and feasibility analyses. These activities rely on well-established and recognized existing infrastructures (*i. e.* high flux reactor (HFR), irradiation rigs, material test facilities) and competences at JRC-IE. Furthermore, a significant effort will be dedicated to facilitating international cooperation (various GIF bodies, INPRO Steering Committee and newly created projects, cooperation, networking including contributions to future FP7-funded projects, participation in conference committees) and to monitoring of European FP6 and FP7 projects.

SAFETY-INNO provides key scientific and technical R&D for the development of selected innovative reactor projects to make them safer, more versatile, more sustainable, more economic and publicly acceptable. The project uses several unique competences and installations and, therefore, participates in European, multinational and bi-lateral cooperation with a reactor project. SAFETY-INNO seeks to identify and to promote strategies that the EU can pursue, separately and collaboratively, for accelerating the development and deployment of innovative nuclear power to reduce air pollution, minimize GHG emissions, reduce EU energy dependence from imports and to promote economic development. Therefore, this project contributes to several FP6 and FP7 competitive projects and to international collaboration efforts with the objective to maximize synergies. Depending on the Euratom participation in Generation IV International Forum (GIF) projects, the results will be made available in accordance with the rules agreed within GIF.

(5) CAPTURE: Knowledge management, training and education in reactor design and operation

Staff ageing and mobility significantly contribute to the loss of knowledge in the nuclear technology area. The experts who took active part decades ago in the designing and commissioning of most NPPs are gradually disappearing from an active role. Knowledge on the original designs, features, and related technology and scientific background is in danger to be lost through the generation gap of the nuclear experts in few years to come, if not partly lost already. The concern is valid in particular for Russian designed NPPs in the new member states, facing the compelling issue of maintaining fundamental knowledge, scattered in many countries and formalised in different languages.

The JRC action aims at gradually covering most EU reactor systems, including PWR, BWR, CANDU, WWER. In addition to the knowledge in each member state, JRC has produced a long standing record of results from its own institutional activities and even more through the participation in a large number of European network partnership projects. In particular, substantial knowledge is available at JRC-IE on plan-life-management (PLIM) topics as well as structural design, nuclear science, structural safety analysis, thermo-fluid dynamic, reactor dosimetry, safety management systems, decision making, organisational issues and human factors, design criteria, super critical water, in most cases relevant for supporting the development of advanced reactor systems as GEN IV applications, see fig. 3.

It is important, beside preservation, to consolidate the enormous amount of scientific results produced previously. This can be effectively done utilising a dedicated method developed at the IE for the consolidation of knowledge. The method is based on the active involvement of those senior experts who have participated since the beginning of the nuclear era and are still active and available. It makes the extensive use of well focused consolidation workshops and has been tested in recent years achieving encouraging results. Training and education material can be developed in this way very effectively for the use in academic organisations.

GEN IV cannot afford to fall into the same shortcoming in the future. A systematic approach needs to be developed to start knowledge preservation and slowly entering into consolidation exercises. It has to be noted that the development of GEN IV is also based

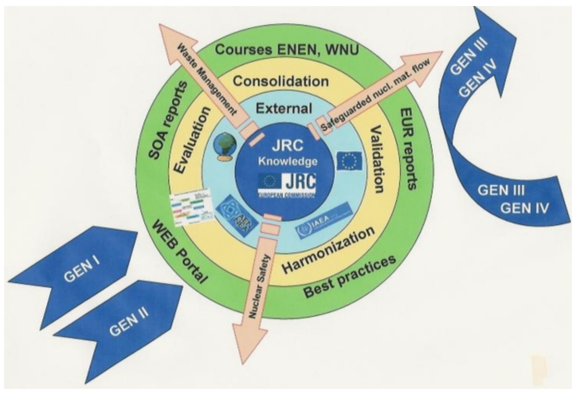


Figure 3. JRC provision of customer-oriented nuclear knowledge

on knowledge created along several decades already and in many cases spin offs of previous generation R&D. The same could be said for fusion, ADS, and other applications.

(6) SAFEWASTE: Waste package and systems for transport, storage and disposal of high-level nuclear waste and spent fuel

Nuclear reactors in the EU generate about 500 m^3 of high-level waste per year in the form of spent fuel or vitrified waste from processing. This waste remains radiotoxic for extremely long periods. The Joint Convention on the Safety of Spent Nuclear Fuel and Radioactive Waste stipulates that the generation that has benefited from the energy is obliged to deal with the waste in a safe manner. A 2001 survey showed that two thirds of the EU citizens would be in favour of nuclear if "all wastes were safely managed". The 2005 Eurobarometer found that a majority of citizens are negative to nuclear energy, but that 40% of the opponents of nuclear energy would change their mind if solutions to nuclear waste issues were found. Clearly, the waste problem needs to be solved if nuclear energy is to be considered acceptable.

The management of spent fuel and nuclear high level waste involves conditioning, transport, storage, and disposal. Beside spent fuel reprocessing followed by vitrified waste geological disposal, spent fuel direct disposal is seen for the moment by some as the most realistic long-term solution. Only few countries are planning to create disposal repositories and storage with different time scales. For the Commission it is a priority that all "nuclear" member states develop and implement disposal or safe long-term storage solutions and that radioactive waste is transported safely. For this reasons implementation of EU wide waste management solutions will require collaboration between EU member states. In this context, a European consensus on, for instance, basic design and performance criteria of waste packages is an important facilitator, in particular for member states with small nuclear programmes.

The action is supporting European policy making and contributing various international working groups (OECD-NEA, IAEA) aimed at achieving consensus on fundamental safety issues and promoting implementation of technical solutions. The technical work is divided into three areas: (a) the design and assessment of waste packages, (b) the integrity of spent fuel cladding under long-term storage and accident conditions, and (c) geological disposal.

(7) AMA: Analysis and management of nuclear accidents

Nuclear energy is currently a part of the energy mix of many European countries. Most countries keep the nuclear question open or show even a renewed interest. Anyhow, nuclear energy will largely depend on the public opinion, and the public is mostly concerned about the related risks due to possible nuclear accidents or nuclear waste. New innovative nuclear reactor concepts can reduce such risks by reducing as much as possible long-term nuclear waste, and by lowering the risk of any possible accident by using inherent safety features in the reactor design.

To support future innovative reactor concepts AMA will use its current knowledge and expertise in nuclear reactor accidents, thermal-hydraulics, risk assessment and related areas with the aim to study the safety of innovative nuclear reactor systems and their application. The focus is on thermal hydraulics of super critical water reactor (SCWR) and the safety of nuclear hydrogen production. AMA represents the JRC in the integral PHEBUS FP programme, an international severe accident programme for current and advanced light water nuclear reactors, and in the International Source Term Programme (ISTP). JRC co-manages the programmes and participates in interpretation circles. The other activities of the action deal with hydrogen safety and probabilistic risk assessment. These activities are relevant to the safety of current generation nuclear power plants.

AMA participates in two networks of excellence (NoE), SARNET (nuclear), and HYSAFE (non-nuclear), where it exploits the JRC knowledge on computational fluid dynamics (CFD) and hydrogen safety to tackle safety issues related to hydrogen combustions. The competence and tools in this field are also applied to non-nuclear hydrogen safety and application questions in collaboration with SYSAF, the non-nuclear JRC-IE action Systems for Alternative Fuels. Moreover, probabilistic methods are used in the area of NPP ageing where AMA runs the Aging-PSA network. Uncertainty methods are applied in the NoE SARNET, the integrated project PAMINA, and the strep ARGONA.

Nuclear safety activities at the JRC Institute for Transuranium Elements

(1) SCNF: Safety of conventional nuclear fuels

The safety of nuclear installations remains a major public concern even if energy production by nuclear fission is considered a mature technology. Licensing authorities are vigilant and push for safety improvements whilst industry is pressed to increase operational efficiency and must constantly integrate new developments. Recent examples are the extension of the lifetime of fuel in the nuclear reactor and the development and testing of new fuels designed to reduce the stockpiles of plutonium. The understanding of the behaviour of nuclear fuel under incident and accident conditions enables the improvement of the response and precautions to be taken if such events occur.

SNCF objective is to contribute to nuclear safety improvements by studying in detail phenomena that occur in light water reactor fuel rods at the extended times of operation and which may endanger the integrity of fuel rods. More specifically, the studies concentrate on technical factors that limit the achievement of higher burn-up of fuel, such as fuel-cladding mechanical interaction, external oxidation of the zircaloy cladding and resulting hydrogen pick-up, phenomena related to the structure of heterogeneous MOX fuel and enhanced fission gas release and its association with the formation of the high burnup structure. The detailed investigations of fuel behaviour under reactor accident conditions are also preformed.

The experimental investigations also deliver input to the fuel performance code, TRANSURANUS. ITU continually updates the models and improves the sub-routines of this code to the benefit of safety authorities in the European Union and candidate countries. The code TRANSURANUS will be further developed to model MOX fuel and very high burnup UO_2 under transient conditions. Other specific objectives are the extension of the database on the thermophysical and mechanical properties of UO_2 and MOX fuel and confirmation that fission gas release from the high burnup structure (HBS) is low, the measurement of the relative proportions of fission gas in the HBS retained in the porosity, in the fuel grains and on grain boundaries, and the study of the thermal creep properties of nuclear fuel, the fracture toughness and the mechanical stability of the HBS.

(2) SANF: Safety of advanced nuclear fuels

This action forms a part of the EURATOM contribution to Gen IV International Forum (GIF). Fuel safety aspects of the Gen IV Gas, Sodium, and Lead (GFR, SFR, LFR) reactor systems are studies via a comprehensive set of investigations covering basic fuel properties, fuel coolant and cladding interactions, and irradiation behaviour, with the final goal of establishing safety limits for fabrication, and in pile performance of the advanced fuels for these reactor systems.

Fuel fabrication methods are developed for the safe production of nitride, carbide, and oxide fuels containing minor actinides, in both homogeneous and heterogeneous recycling strategies. The phase diagrams of these fuels in the major regions of interest are investigated and thermodynamic properties (free energy, thermal conductivity, melting point, helium, and vaporisation behaviour) determined along with fuel/cladding and fuel/coolant interactions. The deterioration and recovery of these parameters in fresh fuel due to irradiation by alpha emitter dopants will be used to complement detailed post irradiation examination (PIE). Through international programmes and indirect actions, new irradiation programs and PIE with Gen IV fuels will be initiated under the specific conditions appropriate for the specific reactor system (cladding, operating temperature, *etc*.). The integration of the information and the development of models to predict the performance of these fuels are necessary steps in the determination of the in pile operational limits of these advanced fuels.

In particular, a very high temperature reactor (VHTR) possesses a high level of inherent safety. The testing of irradiated coated particles and fuel compacts (UO_2 based) under the loss of coolant and air ingress conditions (in the KÜFA and KORA facilities, respectively) is performed. Further examinations envisaged include the microstruture of the irradiated fuel and investigations of failure mechanisms. In a new undertaking, the fabrication of coated particle fuel is developed at ITU, both for U and Pu based fuels and also for fuels bearing minor actinides. Advanced kernel preparation methods will be investigated and a chemical vapour deposition (CVD) coater system deployed to produce the coating layers. The influence of helium in such coated particles will also be assessed. Through international programmes and indirect actions, irradiation testing and PIE of these advanced coated particles are planned, with the aim to establish the limitations in their performance.

RECENT ADVANCES AND EXAMPLE OF RESULTS

As an example of recent results, a semi-mechanistic model development for radiation embrittlement is reported. The model, based on three additional contributions [11] works very well on model alloys for which it has been developed in the first instance. After deep analysis, the model has also proven to be very suitable for modelling WWER-440 materials [12] with low nickel, see fig. 4.

The effect of nickel is that it can significantly enhance radiation embrittlement in model alloys and RPV

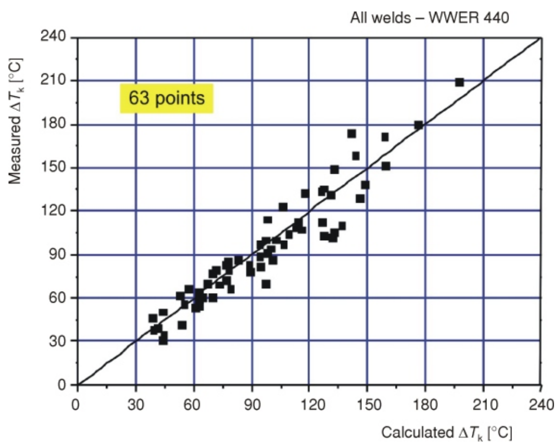


Figure 4. Results of semi-mechanistic model

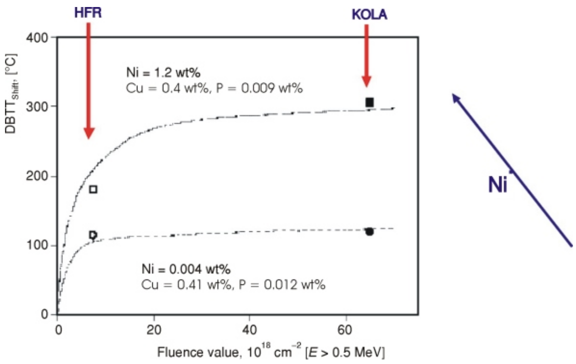


Figure 5. Typical nickel effect observed on model alloys

materials, see fig. 5. Recent efforts to include the effect of nickel into the semi-mechanistic model have been carried out and the results are very good [13]. A further step, after temperature and fluence rate corrections, is to include the effect of manganese. This is done in cooperation with IAEA (CRP-10) and with JRC initiative: model steel and realistic welds programmes.

To give an example of a well established co-operation with the IAEA, a WWER-1000 reference steels action is recently being jointly undertaken by JRC-IAEA and the component is being stored and characterized at the moment at JRC-IE premises for future IAEA actions, see fig. 6.

Figure 6. WWER-1000 reference steel, joint IAEA-JRC action

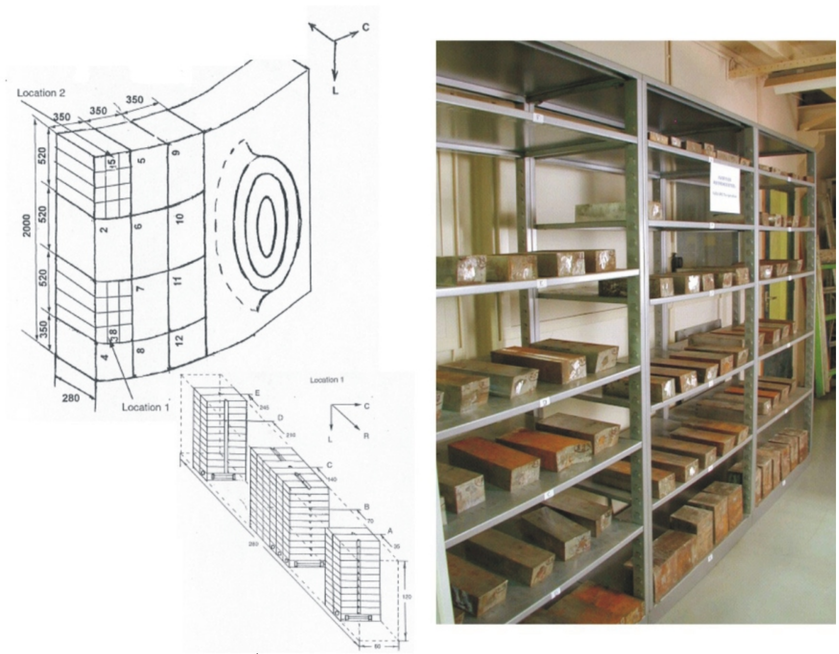
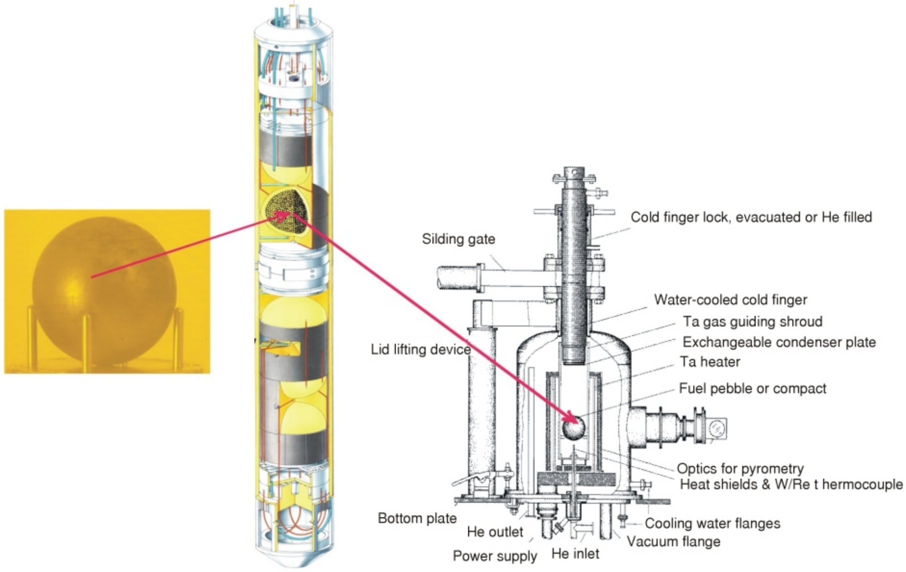


Figure 7. Irradiation test HFR-EU1 in the HFR PETTEN



Another example of recent results consists of the progress achieved with complex irradiations at the HFR Petten, to qualify V/HTR fuel concepts. In fig. 7, a typical example of tailored irradiation rig developed is shown. The rig allows measurement of fission gas release during the normal operation and simulated accidental transients.

An example of activity performed in nuclear design safety is the Network for Evaluating Structural Components (NESC) which is used to promote and manage collaborative international projects that focus on the validation of the entire process of structural integrity assessment bringing together more than 30 operators, manufacturers, regulators, service companies, and R&D organizations.

The network projects are generally focussed on large-scale experimental activities aimed at investigating various aspects of structural integrity assessment, in particular inspection, materials characterisation, fracture mechanics and instrumentation, see fig. 8.

Among the five major projects that have been completed, NESC-III has investigated dissimilar metal welds which are a common feature of light water reactors in connections between ferritic components and austenitic piping systems, see fig. 9. The results show that careful application of available flaw assessment techniques in combination with the improved awareness of the likely tearing behaviour for circumferential cracks at the buttering interface can provide reliable predictions of crack initiation and stability loads for this type of dissimilar weld.

Finally, some results of the JRC action Waste Package and Systems for Transport, Storage and Disposal of High-level Nuclear Waste and Spent Fuel (SAFEWASTE) are reported. In the framework of SAFEWASTE, studies on canisters for the deep geological disposal of spent nuclear fuel have been carried out. The canisters are designed to retain their integrity for at last 100.000 years, which means that the occurrence of future glaciations needs to be considered whilst designing the canisters. The largest design load is thought as a combination of hydrostatic pressure from groundwater, swelling of the buffer material and pressure from a 3 km thick ice sheet, which result in a total external pressure of 44 MPa (440 bar) [14].

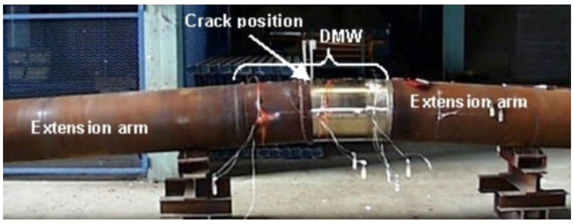


Figure 8. The ADIMEW test mock-up used in the NESC-III project showing: (top) the overall deformation of the assembly after the bend test, which nonetheless remained intact

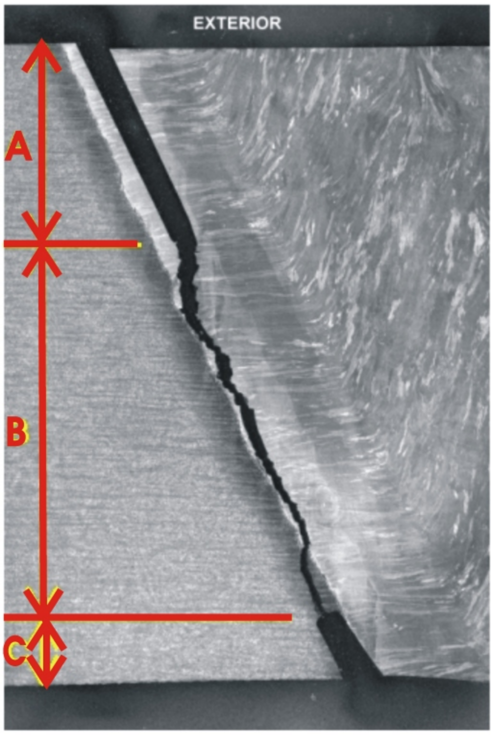


Figure 9. The extent of the crack growth ("B") at the centre of the defect

Studies on the Swedish copper/cast iron canister for deep geological disposal of spent fuel, KBS-3, see fig. 10, have been carried out with the purpose of assessing the failure probabilities at large isostatic pres-

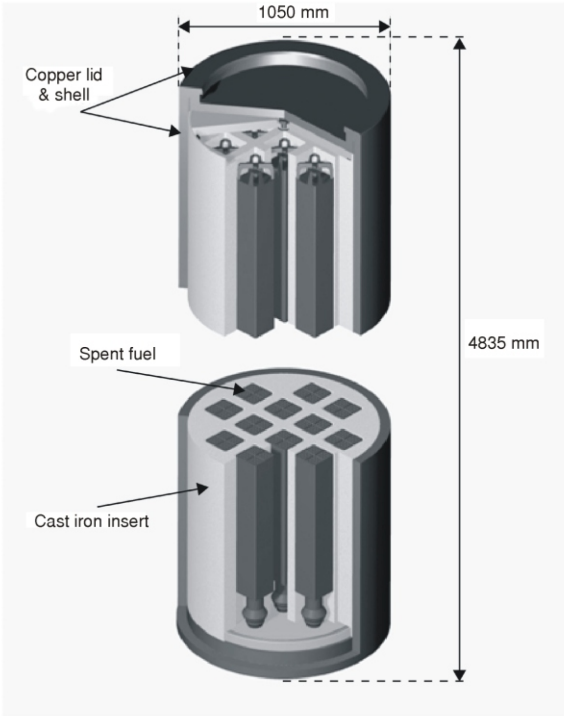


Figure 10. The KBS-3 copper/cast iron canister for spent fuel

sures and producing data for deriving acceptance criteria to ensure that failure probabilities are extremely small. In the case of KBS-3, the cast iron insert provides the mechanical strength of the canister.

The work included a statistical test programme using three inserts to determine the tensile, compression, and fracture properties, see fig. 11. The specimens used for material characterization were also investigated by micro-structural analysis to determine the microstructure and to classify and size defects. It was found that the material scatter and low ductility was caused by many defect types, but slag defects in the form of oxidation films were the most important ones. Those data were then used to compute defect distributions for the probabilistic failure analysis of the KBS-3 canisters.

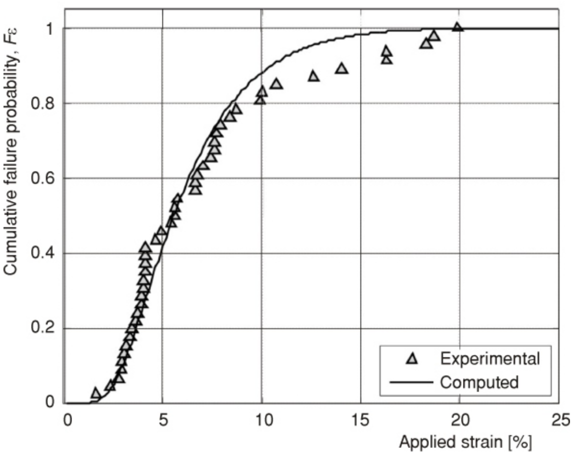


Figure 11. Measured and computed distribution for elongation at the fracture for specimens from an insert

A large number of FE-analyses of canisters were performed at the maximum design load (44 MPa) covering the distributions of material parameters and geometrical features of the canisters. The computed probabilities for fracture and plastic collapse were very low even for material data with low ductility.

Figure 12. Deformed shape of a large-scale component after plastic collapse from iso-static pressure (experimental and analysis)

Two large-scale isostatic compression tests of KBS-3 mock-ups were also performed to verify safety margins. The failure occurred at loads above 130 MPa in both cases, indicating a safety margin of at least a factor three against the maximum design load, see fig. 12. As a result of the project, new acceptance criteria are being proposed for insert geometry and material properties, and the manufacturing process for inserts has been modified to ensure that these criteria are always fulfilled.

CONCLUSIONS

Nuclear energy plays the role as the largest single source of carbon free and base-load electricity in Europe. Sustainability, safety, and security concerns, in particular nuclear safety and nuclear waste management issues, need to be fully addressed in order for nuclear energy to be accepted by the public. The JRC is supporting the EU nuclear safety policy in a EU institutional context, providing reference results and scientific works inherent to nuclear safety. With its research institutes in Petten (Institute of Energy) and in Karlsruhe (Institute for Transuranium Elements), the JRC has been working intensively on nuclear safety, in particular on promoting and developing European networks as NESC, ENIQ, and AMES. Important scientific results have been obtained by the two institutes in particular in the area of materials characterisation, irradiation behaviour, high temperature behaviour and more recently on stress corrosion cracking also in support to SCW applications. These results would have been beyond the scope and capabilities of a single organisations acting independently.

The paper provides an onverview of the research actions performed and in progress at the JRC, and intends to provide a basis for further analysis to the reader.

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Ђустино МАНА, Луиђи ДЕБАРБЕРИС, Андреа БУКАЛОСИ, Роберто МЕЈ, Мајкл БИТ, Ђовани Федериго де САНТИ

ДЕЛАТНОСТ ЦЕНТРА ЗДРУЖЕНИХ ИСТРАЖИВАЊА У ОБЛАСТИ НУКЛЕАРНЕ СИГУРНОСТИ

Данас су у Европи нуклеарне електране највећи појединачни извори електричне енергије која се не заснива на угљу. Поред истицања значаја њихове улоге у укупном енергетском снабдевању, потребно је указати на питања одрживости, сигурности и безбедности, посебно нуклеарне сигурности и управљања нуклеарним отпадом, која утичу на прихватање нуклеарне енергије у јавности. У овом раду приказане су делатности Центра здружених истраживања које подржавају политику Европске Уније у области нуклеарне сигурности. Описана је институционална улога Центра у Европској Унији, одређени различити корисници његових услуга и приказани неки резултати научног рада у њему који се тичу нуклеарне сигурности.

Кључне речи: енергија, нуклеарна енергија, нуклеарна сигурност, Европска комисија, Центар здружених истраживања